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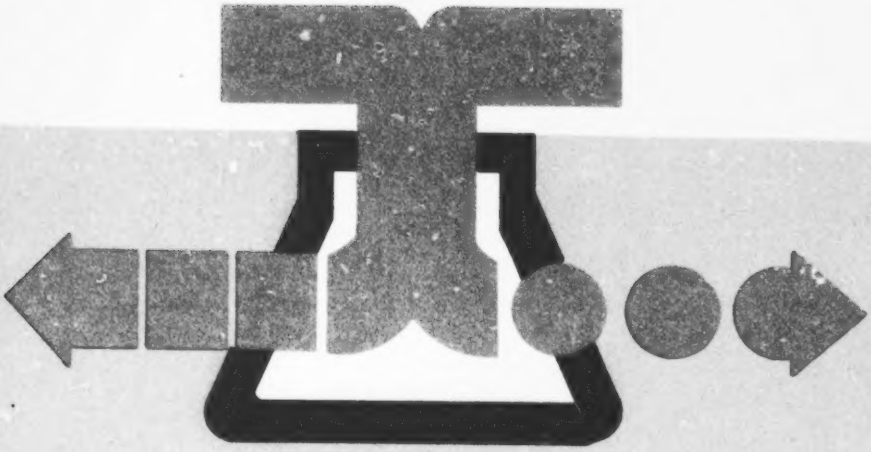

industrial solid wastes management

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PROSPECTS IN TECHNOLOGY FOR RESOURCE RECOVERY

Proceedings of National Industrial Solid Wastes Management Conference

Sponsored by:

University of Houston
and
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Solid Waste Management

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Resource Recovery: The New Dimensions in Solid Waste Management for the 1970's

THE HONORABLE
J. CALEB BOGGS
United States Senator
Delaware

It was not many years ago when we really had very little in the way of effective legislation to deal with the challenge of the impact of solid waste pollution. Our thinking on the challenge of handling solid wastes had not progressed much beyond the invention of the garbage pail. This was true for various types of pollution at that time. For example, the first Federal air pollution research law was adopted just 15 years ago. That landmark even came at a time when I had the honor to serve as governor of my State, and when we had no particularly effective way of handling air pollution problems.

The Federal Government is committed to a program of enhancing the environment, committed with legislation and committed with money.

Without trying to trace down every environmental dollar, I have made a rough calculation that the Administration intends to obligate funds totaling $1,920,000 for pollution control and abatement during fiscal 1971. That is an increase of more than $700,000 from fiscal 1970, and an increase of more than $1,000,000 from fiscal 1969.

The vast portion of that increased obligation came in funds that went in grants to State and local governments, rather than spending made directly by Federal agencies. Thus the increases will go directly to solve local problems.

The spending includes $66,000,000 for the year 1971 for various solid waste programs in Health, Education, and Welfare, Interior, and other agencies, plus spending by various agencies to abate their own solid waste pollution.

President Nixon on the first morning of the new decade said that "The 1970's absolutely must be the years when America pays its debt to the past by reclaiming the purity of its air, its waters and our living environment. It is literally now or never."

That is a challenging call for all of us to follow. Maybe we as a nation have reached the point where we should make a pledge for the future. We vowed less than a decade ago that we would put a man on the moon and bring him back by the end of the 1960's. We met that deadline.

Maybe we should now make a pledge that by the end of the 1970's, we will do something really spectacular, like putting a man into Lake Erie and bringing him out alive.

American homes, factories and farms annually generate 28 tons of solid wastes for every ton of steel that we produce. We have begun to leave junkpiles on the moon and in the depths of the seas. When a Navy Admiral descended 2,450 feet to the floor of the Pacific Ocean off San Diego not long ago, the Navy reported that "The first thing he spotted two feet away was a beer can."

Solid wastes are a by-product of our standard of living, accumulating at a rate more in line with our increase in national income than with our increase in population. A poor nation cannot afford the luxury of waste. Instead, it turns its dumps over to scavengers. America must begin scavenging through its trash, for we cannot afford the luxury of waste.

We confront more than simply a storage problem. We face a health challenge. Doctors have identified a relationship between poor solid waste management and 22 human diseases, one of which is hepatitis. Former Health, Education, and Welfare Secretary Robert Finch explained it this way: "Seepage of toxic materials from improper solid waste disposal has been linked with pollution of both ground and surface water and has presented a grave hazard to future users of those vital water sources."

A great deal of activity seems to be occurring continually in the solid waste field. I hardly pick up a paper without reading of a new recycling process or an improved separation technique.

The State of Delaware has gone so far as to advertise in the Wall Street Journal for a private industry to assist the state in developing a major refuse-recycling plant to handle 500 tons of refuse daily.

The advertisement and the plan for the plant are the result of a study authorized by Governor Peterson of Delaware into the challenge ahead in solid waste management. The imaginative approach suggested by State Representative Robert Berndt and his committee should prove both successful for Delaware and an innovative simulation for other States and areas.

Tentative plans call for a $10,000,000 plant to handle 500 tons daily, about the same volume of refuse now processed at a major sanitary landfill near Wilmington, Delaware's largest city. Operation would begin by 1974, with a profit anticipated a few years later from the sale of the reusable steel, aluminum, paper and other materials that would be sold to industry for recirculation through the economic pipeline.

Each day presents other challenges in the handling of solid wastes, some of which involve just the nature of wastes. The composition of solid wastes is constantly evolving, presenting new difficulties in the efforts to process and recycle municipal refuse. As the glass and paper content of wastes has increased proportionately as a result of this throwaway age, there has been a decline in food wastes, as a result of the increased use of garbage disposals and prepared foods leaving no residue.

During the month of February, 1970, our Subcommittee on Air and Water Pollution had the opportunity to listen to two weeks of testimony on the various pending legislative proposals dealing with the solid waste challenge.

There was extensive and helpful testimony to show the great value of the research and demonstration grant sections that appear in the Administrative proposal and S. 2005, Senator Muskie's bill. This is vital work.

We heard extensive arguments on the subject of Federal grants to municipalities for the construction of solid waste disposal facilities. This is the major difference between the Administration proposal and that offered by Senator Muskie. While the Nixon proposal emphasizes research and demonstrations, Senator Muskie's bill provides grants up to 50 percent for the construction of solid waste disposal facilities. The recent hearings revealed strong arguments for and against the grant approach. Such grants would help local areas install the latest and best facilities. But grants might undermine the role of private initiative in the field, tending to siphon off private investment. Grants might also tend to delay activities in some areas, while governments awaited the Federal money. And there is a philosophical point, the grants would tend to emphasize disposal at the expense of recycling.

Yet if there has been a theme that has run through the testimony it is the urgent need to encourage recycling of our solid wastes.

One witness offered this equation to demonstrate the extent of the recycling benefits: "Every time we fail to reuse one ton of iron or steel in a junked car, it takes two and a half tons of new ore, a ton of coal, and 2,000 gallons of water to produce the replacement ton of iron ore."

Our nation must begin to utilize an increasing percentage of our wastes. Sir George Thomson said: "What we should do is to recover used materials even when not economic at present prices — a process rather like planting oak trees for future generations."

This is an apt analogy. Each time we reuse a ton of waste paper fiber blending it into secondary paper products, we preserve 17 trees from the woodman's axe.

The President, in his environment message of February, 1970, laid great stress on the need for increased recycling research. Specifically, he urged the "redirection of solid waste research toward techniques for recycling materials and producing packaging materials that are easily degradable."

There are some unusual methods for reusing solid wastes. In Washington, D.C., an exhibit at the National Collection of Fine Arts is created largely out of junk: bald tires, broken chairs and rusty machinery. These hunks of junk are put together in a fanciful design called modern art. The design certainly must be interesting, for the visitors cannot be coming to see what a bald tire, a busted chair, or rusty machinery looks like.

We cannot count on museums to warehouse our solid wastes. That would soon convert the world into an art gallery.

Rather, we must concentrate on ways to process wastes in the way that is most effective in extracting the reusable portion, then disposing of the residue in the least damaging way.

The cost will be high. But the cost would be higher if we do nothing. The $4.5 billion annual price for the handling of solid wastes in our nation does not take full account of the very substantial costs to industry and to farmers for handling wastes, nor does it calculate many intangible costs, such as the cost to a family for the space it needs to store wastes at home. There are declines in property values for homes located near an unsanitary landfill, and the psychological damage to our society from the accumulation of solid wastes in slum areas, a cost that cannot be weighed in silver.

The real cost to our nation could be billions higher. This is the high cost against which we must balance the price for improvement in the handling of our solid wastes.

Thus I think we have several goals that we must attempt to achieve.

We must continue to improve the efficiency of waste management — both the quality of service and its coverage across the country. We must do more to reduce the high accident rate that still affects solid waste operations in some areas. And we must press forward to improve our technology for treating solid wastes.

I am intrigued about a process being tested in Texas that would use chopped up rubber tires in road asphalt.

The vortex incinerator being tested in Indiana under a Bureau of Solid Waste Management grant shows promise, with its system for burning refuse that is suspended by air. Combustion Power Company's incineration unit converting refuse to electricity is most impressive.

Such innovative ideas naturally receive wide and deserved attention. They must continue to receive strong Federal support, for they will uncover the answers for the future, the ways to handle the wastes we will produce for the future, and the ways to handle the wastes we will produce ten or twenty years from now.

Once I received a letter from Ed Cliff, the Chief of the Department of Agriculture's Forest Service. What was unusual was the paper on which it was written, for a large percentage of the fibers that made the paper were reclaimed from the Madison, Wisconsin, landfill.

In the meantime, until these many gains can be expanded into production, our wastes will continue to accumulate. We must, therefore, attempt to modernize our current techniques for handling wastes, to carry us through any transition period until we reach some of our technical goals.

And the answer definitely is not the signs I remember hearing about when I had the honor to attend a solid waste conference in Louisville. I'm told there were several signs erected in Southern Ohio that read:

"Fight Litter, Dump Your Trash in Kentucky."

Actually, we must look at the problem, along broad lines, for the issue of solid wastes is woven through the entire question of environmental quality.

Many rivers would not be polluted except for the manufacturing plants nearby that make solid products. Much of the air pollution of our nation would not exist except for the burning of solids that might otherwise be trucked to a landfill. The interrelation does not end there.

Our success in combating other environmental pollutants will accelerate our solid waste challenge. As we scrub more and more dust and gasses from our air, we accumulate more and more bins of solids needing land disposal. As we clean up our water effluents, we increase the accumulation of sludge that often must be disposed on land.

Increasingly, we must begin to look at pollution from all its angles, not just from how it degrades the water or how it smogs the air. Virginia's new governor, Linwood Holton, expressed it well the other day: "We ought to have streams so clean we can see the beer cans, then we have to get the beer cans out."

The Bureau of Solid Waste Management has initiated studies of the economic factors present in the salvaging of materials, studies that will supplement their exhaustive efforts to upgrade technology. They have reached no conclusions yet, but this is an essential program. It is an example of the forward-looking approach the Bureau is taking, an approach that I believe we must seek to encourage as best we can.

We have many ways to promote this interrelated approach. President Nixon has directed all Federal agencies to review their grant programs involving pollution control to see how they can be modified to encourage comprehensive environmental planning. A White House Council, headed by industrialist Roy Ash, will soon recommend a possible reorganization of the pollution abatement agencies in an effort to promote greater efficiency.

We should seek to improve regional coordination of solid waste programs in some areas. In the state of Delaware solid waste management is fragmented among 107 public and private collectors.

There is a desire to insure continued strong reliance upon the private sector in our struggle to meet the solid waste challenge. We have heard some very persuasive testimony before our Subcommittee for the creation of large solid waste collection and recycling services, much as electric or natural gas utilities serve a particular region for profit now.

But there continues to be a need for coordinated planning in handling our problems.

In his important study for the President's Office of Science and Technology, Rolf Eliassen declares:

"Planning calls for a long-range look at the total area involved. Communities are inclined to conceive of solid waste collection and disposal activities in terms of how to deal with community refuse for the next few years. Communities might best consider and act in terms of what must be done to meet the total area needs for 25 or 50 or even 100 years."

Some 41 states, including Delaware, have established state agencies to inventory their wastes, and to initiate programs for the improved management of those wastes. Several states have gone farther, adopting laws giving the state agency authority to approve solid waste facilities within the states.

This moves in the direction of standards, which I believe we must encourage. In testimony last fall, Administrator C. C. Johnson, of HEW's Environmental Health Services, urged the Subcommittee to write language establishing a procedure for setting national standards in the collection, treatment and disposal of solid wastes.

Such standards should pose no hardship on any community or company, but would insure that their collection and landfill operations meet the highest reasonable level in order to protect the local environment.

To foster comprehensive planning, I have had the honor to offer an amendment to Senator Muskie's bill, an amendment that Senator Muskie and most other members of the Subcommittee have graciously co-sponsored. It would establish a National Commission on Materials Policy.

For some time, as a result of my interest in pollution abatement, I have sought out methods for reducing the accumulation of trash at the production stage, rather than worrying about it at the disposal stage. I am convinced that one of the most effective ways would be to develop a national materials policy, a policy that, among other things, would encourage manufacturers to use materials that easily recycle or degrade.

Over the past couple of years I have had the good fortune to receive two knowledgeable reports on this subject, reports prepared under the direction of the Library of Congress. The second, which was more detailed than the first, was called Toward a National Materials Policy. It makes this point: "It is of the utmost importance that, from the initial steps of production of materials through the ultimate use and disposal, we conduct our operations and activities in such a way as to minimize pollution of air and water and to avoid despoliation of the environment both physical and biological."

Our amendment would establish a two-year commission to examine materials from all their angles and all their problems. The Commission would then recommend courses of action to the Congress.

Some objections have been raised that the need for a materials policy is so great that we should immediately give this policy examination to an existing permanent government agency.

I believe a statement that appears in the Library of Congress study meets that point: "A Commission appears to give the most reasonable chance for rapidly bringing into focus issues in material policy on a timely basis which would then be given continuing consideration by some more permanent institution of government."

In addition, it would attract the best minds within and outside government to assist in proposing a timely national policy.

Another way to augment our efforts in dealing with solid wastes would be to place more realistic charges on our production of solid wastes.

Too little distinction in price often exists between the person who generates great volume of solid wastes and the person who creates very little solid wastes. We had a great deal of testimony before our Subcommittee on the need for working out a program that would distribute solid wastes collection fees more equitably, particularly for the homeowner. I do not have the answer, but I urge you to consider this question.

There is no logic to a system under which I pay no more than my neighbor does for garbage collection service, although my family may fill two or three times as many garbage cans weekly as my neighbor does.

I was also very impressed by the testimony before our Subcommittee calling for the imposition of a penny-a-pound disposal fee for all manufactured goods. This proposal was presented in some detail by Leonard S. Wegman, a New York consulting engineer. It would tax the final manufacturer 70 cents for a 70 pound chair, for example, or $30 for a 3,000 lb car.

Former Secretary Finch, in testimony before our Subcommittee last fall, suggested such a poundage tax on products that could be expected someday to end up as solid wastes. The money would be used to finance new and improved waste disposal processes. Secretary Finch argued that this would be more equitable than paying for such increased efforts from the general revenue.

It would seem that such a levy might be considered. The consumer now pays for the design of the article as well as for its distribution cost, and the cost of its sale. It might not prove a greater burden to ask him to pay for its return to nature.

Tax policy could be a tool for the disposal of other products. Former President Johnson's Science Advisory Committee as long ago as November, 1965, recommended the creation of a tax to provide an incentive for eliminating the long-term storage or holding of junk automobiles.

A new President took a new approach. President Nixon in February urged the development of what he called "bounty payments" to insure prompt scrapping and recycling of the several million cars we junk annually.

One Delaware expert goes farther. He recently told me that he is convinced that we will reach a time when the company that manufactures an object will be legally responsible for disposing of it at the end of its useful life. Such a requirement would go far toward encouraging manufacturers to engineer their products for easy disposal.

But the area in which we may be able to make the greatest gains will be through improved collection systems. The collection of solid wastes constitutes an estimated 75 percent of the cost for handling, moving it from office to incinerator. If we succeed in moving to more efficient technology for processing the wastes at a disposal center, we might be able to pay a large share of the expected higher cost with improved collection systems. Some municipalities today spend as much as $20 to collect a ton of refuse and deliver it at a disposal plant. If that figure could be reduced by as much as 25 percent through more efficient collection methods, the funds would finance a greatly expanded and improved system for returning those wastes to the environment in a form that presents the least possible hazard.

This does not mean that we must suddenly install Buck Rogers collection systems, whisking wastes to a central processing site, rather like a vacuum cleaner.

But it does not seem to be too much to ask homeowners to separate garbage, at least into paper products and non-paper products to facilitate processing and recycling.

Several members of our Subcommittee on Air and Water Pollution appeared to be most intrigued to hear of an experiment that utilizes a specially designed garbage truck operated efficiently by a single individual. This high-paid technician never has to leave his seat. The operator works from a right-hand-drive seat. He can swivel to reach down and pick up the garbage, then place it on the truck. He can then swivel back to drive on to the next house.

Progress, however, need not prove as fancy as a truck with a swivel seat. The State of Delaware has many rural areas where solid waste programs need attention. Some areas might move toward a system like the one developed in Chilton County, Alabama. That Alabama county is about half the size of the state of Delaware and has a population of 27,000 persons. Until the Bureau of Solid Waste Management offered the county a demonstration grant, the county had no solid waste program. Residents hauled their solid wastes to several burning dumps scattered around the country.

The Bureau of Solid Waste Management funds enabled the county to open a sanitary landfill and set up containers at each of the former dump sites for collection of refuse. Such a simple, yet effective, program can prove a boon to waste management in hundreds of rural areas.

Systems like this, simple developments requiring no great technological breakthrough, will go far to improve the efficiency of our solid waste systems while we are perfecting more sophisticated disposal techniques.

The most populated county in Delaware is studying a plan to purchase shredding devices to reduce in volume the daily collection of refuse that would require landfill disposal.

This is an excellent program, and I would hope that other areas would follow the lead of New Castle County in utilizing machinery to extend the life of existing and proposed landfill areas. These shredders would also accelerate the degrading of landfill materials to their natural state in the earth.

But this cannot be the ultimate answer. Shredders and the collection bins and other innovations are merely a first step — a big first step — toward increasing recycling of wastes. Our goal must be recycling. The challenge America hands to the people is the need to foster greater and greater recycling.

No greater social and material goal could come from this decade than the technology to recycle the bulk of our wastes, enabling us to take the materials that benefited society once, and make them benefit society again.

That is the task you are handling, as you accumulate knowledge to accomplish an even more effective job.

Make no mistake, the public is strongly behind you. The public appreciates your problems, and it urges you to find solutions that will benefit all of us. Hardly a day seems to pass in which I do not receive a fist full of letters from high school students pleading for environmental action. Or I might visit with a group of high schoolers who have a petition that a lot of their friends have signed.

We have already achieved a sound base on which to produce the progress they so urgently desire. Certainly, the perception of the Bureau of Solid Waste Management in supporting conferences like this one show that the federal bureau most intimately involved in solid waste problems is doing an excellent job both with the hardware and with the ideas.

One day, not long off, we will all wonder where the solids went.

Industrial Utilization of Secondary Resources from Solid Wastes

VICTOR BROWN
Metropolitan Waste Conversion Corp.

On the subject of industrial utilization of secondary resources from solid waste, there is the understanding that a great deal of recovery is practiced throughout the nation by the secondary materials dealers covering almost every possible and conceivable type of material. Private waste material dealers and processors now play a very significant role in helping to cope with the nation's solid waste problem. This has not always been thought of in such terms, but the truth of the matter is that whether or not one has considered it in the past, or whether or not one likes to fit it into this category, anyone who handles or deals with waste material plays a role in the solid waste business. Waste is any by-product connected with society's activity for which there is no desire to keep it on the part of the immediate owner. Therefore, in any point of time when a discard is made of an item as worthless, it has become a member of the solid waste family. However, by the ingenuity and energy of the secondary materials industry, a great volume of many commodities has been rescued from the waste category and installed into the position of a respectable and desired commodity ready to be recycled for added useful purposes.

The difference today relates to the new urgency of considering the need for salvaging and recycling. The nation has been sharply brought to the attention to consider the responsibility of recycling versus disposal. Solid waste and particularly the recovery and utilization has dramatically become a key domestic issue. A sharp focus on recycling and reuse of materials as opposed to disposal of waste has been sounded from the White House down through federal and state bodies as well as a great segment of industry itself. This appears to be an awakening on the part of the nation itself with a new understanding of responsibility to account for a great wastefulness practiced over many years and which now must be remedied.

Mr. Migdoll, writing in the American Metal Market in behalf of the National Association of Secondary Materials Industries, stated, "The change in emphasis in the government from disposal to recovery of solid waste has been a swift and dramatic one. At last, the government has become concerned with how to reuse secondary materials instead of how to get rid of 'junk'." It is easy to understand that the secondary materials industry and in particular the processor of secondary material has a major stake in the reuse of various commodities extracted from solid waste. Richard Vaughan recently commented that "private scrap dealers and processors now play a very significant role in helping to cope with the nation's solid waste problem. The importance of their service to society as well as business opportunities for the scrap industry may be expected to grow even larger in the future." These things we expect, and they will naturally follow growing emphasis of solid waste utilization. However, there is a much greater factor of responsibility by industry on the subject than herewith mentioned, and this reaches back into the basic industries of our nation.

Industry and commerce have already felt the heavy hand of reaction against all obvious pollution practices of which almost all segments of industrial activities are guilty. Coming out loud and clear, however, is also the cry against indirect pollution by industry through its user customer. Since it is more proper today to refer to the ultimate customer as a user rather than consumer, this is certainly very apropos and relative to the question of solid waste generation. A considerable part of concern today relates to the disposition of a great host of manufactured products which very quickly find their way into the solid waste glut. The prime example is the packaging industry's effect on land pollution and litter. The glass container and can industries are now extremely sensitive to the mounting public clamor which could bring reactionary economic reprisals to them. Although these rigid packaging industries appear to be in the direct line of the current fire, certainly the paper industry, being by far the largest contributor to the volume of municipal solid waste, has already been brought under study. Paper and fibre have always been prime materials around which to design the short life product. The intensity of today's pursuit of quick obsolescence aggravates the problem of dealing with these solid wastes.

A well thought out session on industry responsibility in the area of solid waste management appears in the report which has just been issued for review entitled "A Program Plan for Solid Waste Management in California - 1970."

"Private industry has a broad base of affiliation with solid waste management. This affiliation must account for: (1) industrial and agricultural activities as sources of solid wastes; (2) producers of consumer products which may eventually become waste; (3) private service associated with collection, transportation and disposal of solid wastes; (4) the activities of salvage and reclamation of waste products through secondary materials industries; (5) manufacturers and suppliers of equipment used in solid waste handling, and (6) consulting firms which serve as the planning function in solid waste management. To be effective, a statewide program of solid waste management must be cognizant of the capabilities and resources of these entities.

Private industry should develop an acute awareness of the vital role they play in solid waste management. In order for industry to meet its responsibilities effectively it must:

1. Recognize the possible effects of its activities on people and the environment, and develop policies directed toward enhancement of environmental quality.

2. Conduct its operations and activities in manners which do not create health or nuisance problems.

3. Participate in community affairs, public meetings and other functions which concern solid waste management.

4. Work jointly with governmental agencies and contribute appropriate talents toward stimulating, planning, developing and implementing sound solid waste management programs.

5. Keep pace with technical developments and related knowledge in the field of solid waste management and utilize the best available information toward providing the most efficient, effective and economical service to the public.

At the same time, governmental agencies should recognize the capabilities of the private sector in achieving solutions to solid waste management problems, and should utilize these capabilities to the fullest practicable extent."

Private industry should develop an acute awareness of the vital role they play in solid waste management. This vital role is extremely important in the area that industries, and especially the basic industries must be prepared to be the recipient of the recycled resource which can generate and which will come from a great effort in this recycled resource.

Several industries have developed sufficient social concern in regard to the litter disposal of their products and have already taken steps to cope with the situation and protect themselves against the inevitable reprisal control which will ensue. However, it is important that more than the defense mechanism come into play. Rather a real sense of fundamental desire must be fostered to turn a vast liability into a real asset. Strong motivation must get behind the implementation of a massive reclaiming program. Industry cannot in good conscience turn its back on the base supply of basic materials, such as 48 billion metal cans and the 26 billion bottles which are produced and sold for profit every year. The paper industry produces almost 60 million tons of paper every year, but only recycles some 11 or 12 million tons. In the past, these three major industries which are the backbone of the packaging industry have been less than eager to accept any responsibility in finding viable means for reusing this vast amount of material with which solid waste management is expected to cope. Without some tangible and practical action in the additional reuse of the basic items, all of the reports and studies and all the discussions are a waste of time. It is gratifying to note that the glass container industry has launched a strong program and has taken a positive position that the industry will reuse glass brought back to its production centers. This is good and is a major step; however, there remains a lot of hard work to work out the mechanics of gathering the bottles and the jars to develop a regular channel of supply which is easy to follow.

It was reported from Washington that the steel and metal can industries have unveiled a project to demonstrate a new system to collect all used steel containers and recycle them into the production of steel. This will be an example of the kind of cooperation industry must develop in order to help remove the solid waste and recycle it, instead of trying to dispose of it with damage to the environment. There was a report made by George A. Steinson, President of the American Iron and Steel Institute and President of the National Steel Corporation, to the effect that a demonstration project will be scheduled within the next three months at National Steel's Weirton, West Virginia, plant. Mr. Steinson indicated that both the steel and the can manufacturing industries are ready to do their part to make such a program succeed. This is very laudable — this action should have been taken a long time ago. There is a great deal of room for industry to take a leadership role in moving into a situation which is distinctly in the public interest. There has never been any lack of capability to provide a facility which very effectively can extract a great many of the 48 billion cans and channel them back for reuse. There has to be a desire on the part of the basic industry to want them back and not force upon the nation but one alternative of simultaneously contaminating its environment and losing a very valuable national asset.

The paper industry is daily the largest contributor to the municipal solid waste picture. The vast discard which daily is collected up and down our city streets usually contains anywhere from 55 percent to 70 percent of paper or paper products. There is no question but that the cost and technique of gathering up a great deal of this once used paper and channeling it back for reuse by the mills is not an easy job or a popular one. However, the trend over the years on the part of the paper industry has been to use less and less recycled fibre and call for more and more virgin wood fibre for the production of many of the products including a great many of the common category. Certainly adequate technology has been available for a greater utilization of used fibres. Other countries, where there is greater natural incentive for using it, have shown great talent for making high grade papers from the once used fibres. Within this industry there must be a real awakening of social concern in the field of waste recovery. It should be remembered that a great preponderance of the tax dollar used in connection with disposal of solid waste is demanded from the paper waste.

There is a great urgency to coping with the garbage glut, industrial waste glut, the agricultural production glut. Some of these are very difficult to cope with, but with the technology capability for which our nation is so widely renowned, we could very easily and quite quickly be able to open up a large demand for the basic metals, glass and paper which have been relegated for a long time to the unwanted list on the part of industry leaders, solid waste management will respond effectively to make the whole program work for the benefit of government, industry and the public at large. Success or failure of the entire reuse concept of solid waste management lies with the private sector producers of basic commodities.

State and Regional Programs for Industrial Solid Waste Management

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Pennsylvania is currently in the process of completing its plan for a state wide solid waste management system. This plan is based on the development and implementation of eleven regional plans and these in turn have countywide and multicounty plans fed into them. This was made possible through a Health, Education and Welfare solid waste planning grant from the Bureau of Solid Waste Management under Public Law 89-272 (The Solid Waste Disposal Act). During a three year period from 1966 to 1969, Pennsylvania Department of Health conducted a solid waste survey of all of its 2559 municipalities and 80 percent of its 18,000 industrial and agricultural plants. Most of the information obtained from these sources has been summarized and has been furnished to county and regional planning commissions to assist them in developing their plans. The Pennsylvania Legislature in 1968 also recognized the need for a regional approach to solid waste management and passed a Solid Waste Management Act which will be discussed later in greater depth. The Act is referred to at this time only to indicate that it provided for 50 percent grants to local government for planning solid waste management systems and, further, required them to implement their plans. The staff of the State Health Department has provided technical assistance to governmental jurisdictions, private industry as well as nonprofit organizations in the development of area wide solid waste management plans, recycling of waste materials, transportation by rail and truck as well as in the development of studies and investigations of special problems. A few examples of such assistance may be helpful to demonstrate the wide range of involvement and interest of the Department. In Shippensburg, Pennsylvania, the Department of Health assisted with the development of a demonstration project for a new type of incinerator; in Erie County, Pennsylvania, in conjunction with the Great Lakes Research Institute and the Governor's Science and Engineering Foundation, the Department of Health assisted in the development of a proposal for recycling solid waste; in the eastern part of the state, the Department of Health is providing consultation to private industry in the development of long distance rail and truck haul of solid wastes; at Drexel and Penn State Universities the Department of Health is providing both technical staff assistance as well as funding for solid waste research projects. These are just a few of the involvements which the Department of Health has undertaken in fulfillment of its responsibilities.

As a result of the industrial and agricultural survey, information is being revealed that will help work with industry and their local governmental units so that the Department of Health may eventually help them solve their solid waste problems. It is important that one have some idea of the type of information that is being gathered.

As an example let us briefly analyze the pharmaceutical industry in Pennsylvania. There are thirty-one plants ranging in size from one employee to 1217 employees producing 29,570 tons of solid waste annually, of which only slightly more than 3,100 tons are salvaged. The remainder to be disposed of contains materials which are considerably different than those found in residential or commercial wastes as well as those with which one is familiar. A variety of drugs, chemicals, charcoal filters with arsenic, dead animals and mycelium are among the more unusual wastes, and it also contains the traditional cardboard, paper, metal cans, plastics, cloth, incinerator ash and eggs which are the more common constitutents of municipal wastes. The costs of disposal to this industry in Pennsylvania is $37,690 per month.

The potato chip industry is one in which the Department of Health has also made some preliminary analysis. At the time of the survey there were 39 establishments processing potatoes with a total of 18,600 tons of solid wastes per year, of which only 1,000 tons were salvaged. The waste was chiefly composed of organic material, salt and grease and the industry's disposal cost is $8,200 a month. Both of these industries indicated considerable problems and difficulties with both storage and final disposal of much of their wastes.

The relationship of industrial wastes to municipal wastes is reflected in the data from Erie County, Pennsylvania. Our survey revealed that there were 1,158,500 tons of waste produced annually in the county. Of this, 638,400 tons were industrial wastes and 520,093 tons were municipal wastes. When these figures are broken down to pounds of solid waste per person per day it was found 4.6 pounds per person per day for municipal wastes and 6.2 pounds per person per day for industrial wastes making a total of 10.9 pounds per person per day.

The industries in Erie County are an integral part of the county's economy and their planning department considered the needs of these industries in planning for water, sewage and transportation. It is only reasonable that the county administration should also include in their comprehensive plans a solid waste management plan which would meet industries needs as well as their municipal needs. This is the type of approach we have been fostering. Therefore, conceptually, industrial wastes should be considered as an integral part of a community's solid waste problem for it may, and frequently does, affect the health of the population, and pollute the environment in the area of the generating and disposal sites. An example or two will clarify this statement. In Central Pennsylvania there is a chemical plant producing animal feeds with polyvalent arsenic as an additive. The waste material from this process was stored on the surface of the ground in the vicinity of the plant for several years with no thought being given to the nature of this waste material. As a result of this plant being purchased by another company, a chemical analysis was performed on the company water wells, and they were shocked to find over 6,000 ppm of arsenic in the water. The source of the arsenic was evident to them, and the Department of Health also later confirmed it. When this was called to the Department's attention an investigation was undertaken which indicated that the arsenic in the aquifer surfaced into a stream a few miles from the plant, and this stream emptied into the Schuylkill River which is used as a source of water for Philadelphia, and 3.2 ppm of arsenic was obtained from Philadelphia tap water. Of course, a corrective program was developed and this condition no longer exists. Another and simpler example could be given for the agricultural industry in the production of beef and mushrooms wherein the manure and spent compost create unbearable fly problems for nearby communities. Many more examples could be given for different industries to demonstrate the possible health effects on surrounding or adjacent populated areas. Therefore, it should be recognized that there is a need for the local government officials to consider the types of waste generated by the industries within their confines and be assured that safe and satisfactory storage and disposal facilities exist. It is well known there are very few municipalities that have accepted this responsibility and taken the necessary action to eliminate and prevent pollution and health hazards.

If it is considered that political jurisdictions have a responsibility for the environmental protection of its citizens, then it is necessary for them to plan for such protection. This was accomplished in Pennsylvania through state legislation. On July 31, 1968, the Pennsylvania Solid Waste Management Act was signed into law. It provides for the planning and regulation of solid waste storage, collection, transportation, processing and disposal systems. The intent of the Act is to provide the urbanized and urbanizing areas of the Commonwealth with protection from pollution and public health hazards emanating from improper handling of solid waste. The Act provides for the following:

A. Plans: Effective January 1, 1969, the Act requires local government units with a population density of 300 or more persons per square mile to develop and adopt a plan for solid waste management. The plan shall be submitted to the Department of Health indicating: review by local and regional planning commissions, present solid waste practices, a planned solid waste management system and provisions for expansion of the solid waste management system to growth areas. Area and regional systems are provided for.

B. Permits: Effective January 1, 1970, a permit will be required for the disposal or processing of solid wastes. The Act prohibits the construction, alteration, or operation of solid waste disposal or processing facilities without a permit from the Pennsylvania Department of Health.

C. Rules and Regulations: Rules, regulations, standards and procedures which are necessary to carry out the Act will be adopted by the Department of Health.

D. Powers and Duties of Municipalities: Each municipality with a population density of 300 or more persons per square mile shall be responsible for establishing a solid waste management system within its boundaries; and each may adopt ordinances, regulations and standards for the storage and collection of solid wastes. It provides for the municipality to contract with any person or other municipality, county or authority to discharge its responsibilities under the Act.

E. Powers and Duties of the Department: Authorizes the Department of Health to provide technical assistance; to approve plans; to issue, revoke and suspend permits; to initiate, support and coordinate research and demonstration projects; and to establish policy and to conduct inspections.

F. Grants and Reimbursements: The Act authorizes the Department of Health to assist counties, municipalities, authorities or any combination thereof, including municipalities with population densities of less than 300 persons per square mile, by administering grants to pay up to 50 percent of the costs of preparing plans for solid waste management systems.

G. Advisory Committee: The Act provides for the appointment of an Advisory Committee, appointed by the Governor, which may recommend to the Secretary of Health the adoption, amendment or repeal of such rules, regulations, standards and procedures as it deems necessary and advisable. The committee further has the responsibility of annually reviewing the implementation of the Act and recommending such changes as it deems advisable.

In this brief summary of the Act, it is not possible to reflect the legislative intent nor its broad ramifications. It must be emphasized that from its inception the legislation intended to provide a partnership of state and local government with the private sector, and this was accomplished in part through the legislative requirement of the Advisory Committee consisting of representation from four state agencies, six statewide local government organizations, two universities, seven commercial and industrial organizations, two professional planning and engineering associations and a representative of a consumers organization.

Furthermore, the broad scope of the Act is reflected in two of its definitions. Solid waste is defined as "garbage, refuse and other discarded materials including, but not limited to, solid and liquid waste materials resulting from industrial, commercial, agricultural and residential activities," and a solid waste management system is defined as the "entire process of storage, collection, transportation, processing and disposal of solid wastes by any person engaging in such process as a business, or any municipality, authority, county or any combination thereof."

With this as background, it can now be discussed how this Act is being implemented to attempt to bring together government and industry to protect the health of the Commonwealth's population and the environment from solid waste practices.

Initially as required by the Act, the Governor appointed the members of the Advisory Committee. This committee working with the Department staff developed first the guidelines for solid waste management plans required and included, among other things, the location and description of the study area, transportation network, solid waste generated and where they are located, the proposed solid waste management system with schedules for adoption and capital costs. A two year period is provided for the completion and submission of the solid waste management plans. They are therefore to be submitted to us for review and approved by January, 1971.

As mentioned earlier, the permit requirement for processing plants and disposal sites went into effect January, 1970. The implementation of this phase of the Act was initiated with a letter to all operators of processing plants and disposal sites. A list of these operators had been compiled as a result of our solid waste inventory funded in part by the Department of Health, Education and Welfare's Bureau of Solid Waste Management. The letter with an application for a permit was sent registered mail and informed the operator of the permit requirement of the Act and requested the completion of the application and return within 15 days. Over 95 percent of the applications were completed and returned within the specified time. Legal action was taken against those that did not return the application. Injunctive action is being taken against municipalities and criminal action in the Justice of the Peace Court against private operators. Thus far, no cases have been lost. It was inevitable that despite the publicity given the Act and the assurance that the Department would be reasonable in its enforcement, that a certain percentage of operators would challenge it by not applying for a permit. Fortunately, the number deciding to take this route was small.

Upon receipt of the application the site and operation is reviewed by a technical staff which consists of ground water geologists, soil scientists, sanitarians and engineers to determine whether or not pollution hazards exist and the degree to which it meets the operating standards. If there are no public health or pollution hazards, a permit is issued. On the other hand, if there are adverse conditions existing, then these conditions are enumerated in a second letter which requests the operator to submit to the Department a time schedule within 30 days for the correction of these conditions. Operational items such as open burning or depth of daily cover material are exceptions from the time schedules. For such items they are given a week for correction. One of the items requested of all operators is engineering plans and specifications which indicate the design and method of future operations as well as the means of correcting existing adverse conditions. If the time schedule is not submitted within the 30 day period and contact not made for an extension, then legal action is taken in much the same way as indicated for those not submitting applications. Permits are not issued until all pollution and health hazards are eliminated. The discussion of the methodology of approach to this point has been for existing operations. For new disposal sites or processing facilities operators must comply with the uniform standards in the regulations. These standards were developed by the Governor's Solid Waste Advisory Committee in cooperation with the Department staff. They cover general standards for operation as well as specific standards for sanitary landfills, transfer stations, storage, collection and transportation of solid wastes, incineration and composting. Modules have also been developed as guides for planners, engineers, public officials and operators of processing plants and disposal sites. The completion of the appropriate modules provides us with the necessary information to evaluate the disposal site or processing plant and determine whether or not it can be utilized without creating environmental pollution or health hazards. The major difference, therefore, in approach between the existing processing plants and disposal sites and the proposed new ones is the provision of a time schedule for existing operations to comply with the regulations.

As was indicated earlier, the permitting aspect of the Act went into effect January 1, 1970. Therefore, it is too soon to indicate the success that comes with the elimination and prevention of all environmental pollution and health hazards; however, it is not too soon to reflect the excellent cooperation and coordination of the preponderance of industry, agriculture, local and state government.

It is difficult within the short time available to discuss the many facets of the 50 percent planning grants such as the assistance advance, the conditions and procedures developed to obtain the grants, the technical assistance provided the planners and engineers developing local government solid waste plans as well as the assistance of the Pennsylvania Department of Public Health has received from the Bureau of Solid Waste Management of the Department of Health, Education and Welfare. The educational program for industry, local government and the population at large, had to be omitted for it alone could have served as the basis for a paper.

The details of our industrial and agricultural survey and a comparison of our results with those presented by the Office of Science and Technology in the Executive Office of the President in May, 1969, entitled "Solid Waste Management - A Comprehensive Assessment of Solid Waste Problems, Practices and Needs," have not been discussed. The differences in the data presented from both of these sources would be worthy of discussion.

It is undoubtedly clear that solid waste management is moving at a rapid pace in Pennsylvania. We are excited at the imminent prospects of solving our problems through a cooperative community, industry and government relationship. Such a close working relationship is imperative for the successful conclusion of the industrial solid waste problem.

National Goals for Solid Waste Management

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Bureau of Solid Waste Management

One can scarcely pick up a newspaper or periodical today, or turn on his television set, without being exposed to some reference to the deteriorating quality of our environment. Only a few months ago, it seems, anyone who could have readily defined the work "ecology" was either a lexicographer or a specialist in the biological sciences. Now, at least the word, if not its significance, is familiar to nearly everyone.

Some of the recent interest in environmental problems is due to treatment of the subject in the mass media. Dramatic incidents, such as oil spills from ships and offshore wells, have provided railying points for activists in the conservation field. But more than this, any reasonably observant person who travels across this country, must himself conclude that the environmental issue is a very real one, and that we are in imminent danger of losing the meaning of the phrase "America the Beautiful". For those who want to take the most pessimistic view, perhaps we are in danger of losing not only the beauty, but even the very livability of our environment.

How did this come to pass, and who is responsible? Or, a more positive question might be — how can this pollution be halted and the process of environmental deterioration reversed?

The answer to the first question is that we are all responsible — some more than others, to be sure. The present crisis point has been reached, not by design, but by the lack of it. Countless, and seemingly unrelated decisions, on the part of individuals, corporations and government, have been responsible: the decision to buy a beverage in a no-return bottle — and then toss it out of the car window; the decision to construct a manufacturing plant without providing for adequate treatment of waste effluents; the failure to utilize legal authority to insure provision of such basic sanitation services as refuse collection.

If there is any hope on the horizon, it must be in the fact that the problem has at last been recognized. Historically, the United States has shown itself capable of achieving the most monumental and seemingly impossible goals, once a National commitment has been clearly defined and undertaken. It is true that events of crisis proportion are often required to evoke such a commitment. The Manhattan Project may never have been entered into without the impetus of a World War; the voyage of Apollo 11 probably would not have taken place in 1969 without the crisis atmosphere generated in 1957 by the flight of Sputnik I. National commitments by this country have called forth both the Atomic Age and the Age of Space Exploration. With such demonstrated capability, even the most pessimistic must concede there is at least a chance to save our environment, if only we have the will.

It is hoped that, looking back at the year 1970 from some future vantage point in time, it can be said that President Nixon's State-of-the-Union

Address will have had the same historic importance as Einstein's letter to Roosevelt, urging development of the atomic bonb, or President Kennedy's stated goal to "place a man on the moon and return him safely to earth." As President Nixon said, "The great question of the 70's is, shall we surrender to our surroundings, or shall we make our peace with nature and begin to make reparations for the damage we have done to our air, our land, and our water? . . . Clean air, clean water, open spaces — these should once again be the birthright of every American."

Within the framework of overall National policy, operating agencies of government must set priorities and goals for their own activities, to give administrative direction and to serve as milestones for the measurement of progress. The Bureau of Solid Waste Management, within the Environmental Health Service, has set certain agency goals which, if fully met, will contribute in a significant and measurable way to improving the quality of our environment.

Proper handling and disposing of the vast quantities of municipal, industrial and agricultural solid wastes generated in this country is, of course, only one factor in the environmental quality equation. But, it is an extremely important one, with implications not only for pollution control and community aesthetics, but for public health, proper land use and reclamation, economics, and conservation of natural resources.

For those unfamiliar with the exact nature of the Federal interest in solid waste management, a brief outline is given in the provisions of the Solid Waste Disposal Act of 1965 (P.L. 89-272). This Act is the basic legislation under which the Bureau of Solid Waste Management operates. It directs the initiation and acceleration of research and demonstration of new and improved technology for solid waste management. The Act also provided for technical and financial assistance to local and state agencies and others in the planning and conduct of solid waste programs. The Act specifically directs that attention be given to studies of methods for conserving natural resources by reduction of the amount of waste and unsalvageable materials, and by recovery and utilization of potential resources in solid wastes. Specific Federal activities authorized by the Act include research, demonstration of new and improved technology, studies and investigation, grants for state and interstate planning, basic data collection and evaluation and training.

Initial analysis of data collected in a national solid wastes survey reveals that less than 6 percent of the 12,000 land disposal sites meet the recognized sanitary landfill requirements. Of the 300 incinerators in the United States, 75 percent are inadequate. Twelve percent of the population receive no formalized collection service and an additional 10 percent receive only partial services. Out of 8,500 community systems surveyed, representing an estimated 128,000,000 people, over 90 percent have some subsystem that is unacceptable, thereby rendering the total system ineffective and unacceptable.

Such deficiencies in solid waste management have existed for years. As the production of goods and population increases, the problems associated with deficient systems are magnified. For example, it is estimated that the six pounds of solid wastes, now collected daily on a per capita basis, will rise to eight pounds by 1980, unless some positive steps are taken to reverse the present trend.

Two ultimate goals have guided development of the Federal solid waste program since its inception: elimination of the deterioration of the nation's environment caused by the improper and inefficient management of solid wastes; and the need to conserve natural resources and preserve the quality of the Nation's environment by reducing the amount of material which must ultimately be disposed. To this end, we have funded more than 100 demonstration projects at locations all across the country. Approximately 150 research and development projects have been supported by means of grants, contracts, and with assistance by our own technical staff. Forty-nine states and interstate agencies have received grants to plan for solid waste management on state-wide and regional bases. The level of training for personnel in the solid waste field has been increased through short courses conducted by the Environmental Health Service. Technical assistance, and publication and dissemination of research findings have also been a major part of the work of the Bureau.

Bearing in mind the generally low estate of solid waste practices in this country, the Bureau of Solid Waste Management has defined four areas as requiring particular attention to meet overall goals during the period of the next five years:

1. The percentage of the population provided with acceptable storage, collection and disposal services must be substantially increased.

2. Technology must be improved so that all solid waste can be properly managed, with no increase in current unit volume costs.

3. The volume of solid waste must be reduced at the source, permitting the total per capita amount collected to level off by 1975.

4. The amount of solid waste that is salvaged and recycled to the economy must be greatly increased.

Obviously, to achieve these ends, it will be necessary to promote application of the best existing technology, and to perform additional research and development. Specifically, we expect to fund a determined number of projects in the areas of salvage and waste reuse; investigate new systems for solid waste storage, collection, transportation, processing, and disposal; and investigate the physical and psychological problems associated with refuction of solid waste at its source (would people be willing, for example, to forego the convenience of no-return bottles?). Preliminary studies will be initiated concerning the use of incentives as a means of reducing solid waste at its source. Finally, additional effort will be made to apply the systems approach to solving solid waste management problems.

An Engineering Analysis of Classification Systems for Commercial and Industrial Solid Waste

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It is necessary to define industrial solid wastes before analyzing classification systems. For the purpose of this paper, no distinction will be made between commercial and industrial wastes, since the difference is slight. For example, the difference between off-specification plastics and scrap plastic is simply a matter of form and quantity from a given source.

Industrial solid waste is defined by the American Institute of Chemical Engineers as solid and liquid non-aqueous wastes resulting from industrial operations. This can vary from by-product gypsum from fertilizer operations to tank bottoms. Solid materials vary from strip mine residues to off-spec plastics and liquids from viscous oils to ethylene tar with the general characteristics of gasoline. Ethylene tar is a good example of the problem posed by semantics arising out of cant used in various industries. Tar is not ordinarily thought of as a light liquid.

In order to evaluate classification systems, an arbitrary system based upon the premise that engineering is a profession dedicated to the public welfare must be considered. This will be used as a standard of comparison for classification systems in common use.

Figure 1 divides solid waste into three general categories:

a. Resource Recoverable
b. Convertible
c. Non-recoverable

A simple illustration of resource recoverable waste would be an off-spec solvent that could be recovered by redistillation. This category cannot be further broken down because it is best handled by specialists in the field. A convertible waste can be illustrated by ethylene tar that can be given a light hydrogenation treatment and converted to high octane gasoline or feed-stock for an aromatics plant. By-product gypsum can be converted to ammonium sulfate or sulfuric acid and lime as is frequently done in Europe and Japan. Again, each problem must be considered separately. This leaves wastes that are non-recoverable which at times may include some materials from the first two categories because of economic reasons.

The non-recoverable wastes can be divided into two main categories:

a. Hazardous
b. Non-hazardous

Hazardous wastes are broken down according to the National Academy of Science System devel-

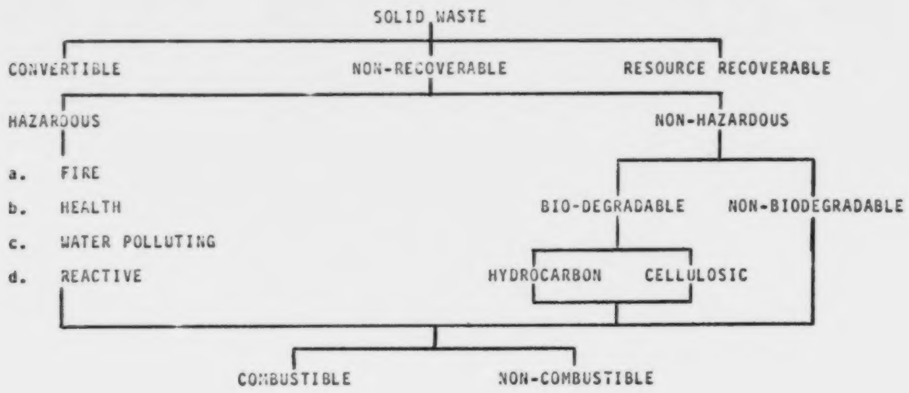
SOLID WASTE
CONVERTIBLE
NON-RECOVERABLE
RESOURCE RECOVERABLE
HAZARDOUS
NON-HAZARDOUS
a. FIRE
b. HEALTH
c. WATER POLLUTING
d. REACTIVE
BIO-DEGRADABLE
NON-BIODEGRADABLE
HYDROCARBON
CELLULOSIC
COMBUSTIBLE
NON-COMBUSTIBLE

Figure 1

oped for the U.S. Coast Guard. The four broad hazard categories are further broken down into ten specific hazards:

TABLE 1

1. Fire hazard
2. Vapor irritant health hazard
3. Liquid, solid irritant health hazard
4. Poison health hazard
5. Human toxicity water pollution hazard
6. Aquatic toxicity water pollution hazard
7. Aesthetic effect water pollution hazard
8. Reactivity hazard with other chemicals
9. Water reactivity hazard
10. Self-reactivity hazard (spontaneous combustion)

The application of the NAS system to solid waste handling and storage is self-evident. Figure 2 from McConnaughey, Lakey and Goldman[1] is a guide to the compatibility of chemicals which illustrates this direct applicability. Table 2 prepared by the Battelle Memorial Institute for The Society of The Plastics Industry, Inc.[2] summarizes the decomposition products of plastics which includes a number of highly toxic products.

The use of the NAS system would extend to solid waste the "maximum credible accident" concept initiated by the AEC. Under this concept, a credible accident is one that does not violate the

X Represents unsafe combination for storage.

1. Inorganic Acid	1																								
2. Organic Acids	X	2																							
3. Caustics	X	X	3																						
4. Amines & Alkanolamines	X	X		4																					
5. Halogenated Compounds	X		X	X	5																				
6. Alcohols, Glycols & Glycol Ethers	X					6																			
7. Aldehydes	X	X	X	X		X	7																		
8. Ketones	X		X	X			X	8																	
9. Saturated Hydrocarbons									9																
10. Aromatic Hydrocarbons	X									10															
11. Olefins	X				X						11														
12. Petroleum Oils												12													
13. Esters	X		X	X									13												
14. Monomers & Polymerizable Esters	X	X	X	X	X	X								14											
15. Phenols			X	X			X							X	15										
16. Alkylene Oxides	X	X	X	X		X	X							X	X	16									
17. Cyanohydrins	X	X	X	X	X		X									X	17								
18. Nitriles	X	X	X	X												X		18							
19. Halogens			X			X		X	X	X	X	X	X	X	X				19						
20. Tetraethyl Lead	X			X	X	X	X								X				X	20					
21. Phosphorous	X	X	X															X		X	21				
22. Sulfur, Molten									X	X	X	X				X						22			
23. Acid Anhydrides	X		X	X		X	X									X	X	X					23		
24. Carbon Disulfide	X			X															X					24	
25. Epichlorydrin	X	X	X	X										X	X				X		X		X	X	25

Figure 2: A Guide to Compatibility of Chemicals for Storage (1)

TABLE 2
Summary of Decomposition Products of Plastics (2)

		Analyses, Percent Volume							
Material	*Method of Testing*	*Carbon Monoxide*	*Chlorine*	*Hydrogen Chloride*	*Carbonyl Chloride*	*Hydrogen Cyanide*	*Ammonia*	*Hydrogen Sulphide*	*Nitrous Fumes*
Rubber	Insulation on cable in 5-1 flask	3.4-7.6	--	--	--	--	--	0.1	--
Foamed polyvinyl chloride	2-3 g heated electrically in 270 1 air	0.023 0.040	0.0	0.005 0.023	0.0	0.001 0.003	0.002 0.003	--	0.001 0.002
Foamed acryloni-trile		0.041	0.0	0.002	0.0	0.002	0.002	--	0.002
Phenolic resin with fillers		0.017 0.046	--	--	--	0-0.003	0.002 0.110	--	--
	As above								
Melamine resin with fillers		0.012 0.07[illegible]	--	--	--	0.002 0.25	0.006 0.180	--	--

laws of chemistry and physics. Statistics are ignored and the only criteria is the greatest level of damage. This would be an extension of projects currently being carried out by the Bureau of Mines and the National Academy of Sciences.

The principal solid waste classification system in use is that of the "Incinerator Institute of America".[3] This is an incineration classification system which breaks down wastes into seven categories.

TABLE 3

Type	*Description*
0	Trash
1	Rubbish
2	Refuse
3	Garbage
4	Animal Remains
5	Gaseous to semiliquids*
6	Semisolids to solid*

*Industrial

It is readily seen that its great weakness lies in industrial solid waste. This fundamental weakness arises from the mechanical rather than the process approach. Industrial waste is classified solely on whether or not it needs a hearth or grate. However, until types 5 and 6 are reached the classification is sound. Table 4 lists the significant parameter.

The I.I.A. is an excellent standard for commercial waste but is virtually useless for industrial waste.

TABLE 4

Type	*Moisture Per Cent*	*Ash Per Cent*	*BTU/LB As Fired*
0	10	5	8500
1	25	10	6500
2	50	7	4300
3	70	5	2500
4	85	5	1000
5	Varies	Varies	Varies
6	Varies	Varies	Varies

Additional weaknesses are that the maximum temperature specified for calculation is 1400°F and the lack of explosion proof electrical fittings. The minimum temperature should be 1800°F. Electrical fittings should be in accordance with the National Electrical Code, explosion proof, Division 2, Class I. However, none of this should detract from the value of the Incinerator Institute standards for the purpose for which they were intended. They are very soundly conceived on velocity and detention time, or in the chemical engineers' language, space velocity. The empirical factors apparently approximate the kinetic constants of which there is no knowledge.

While COPE is a resource oriented company, an evaluation of most available wastes by a technique similar to DARE (Decision Alternative Ration Evaluation) as developed by the Bureau of Solid Waste Management[4] indicates most wastes will be incinerated or used as landfill. The largest factor is development time.

Primarily, the classification uses the parameters of moisture, ash and BTU content. Depending on physical state, the analytical techniques are specified as those ASTM methods for coal or petroleum. Also considered are corrosives which may cause tube wastage in cold wall incinerators and alkalies or other fluxing agents which may destroy refractories. Other items considered are toxic or hazardous substances. The production of polyurethans, for example, produces considerable quantities of lachrymators which require special equipment for handling.

The COPE Classification system, like the Incinerator Institute standard, classifies wastes by numbered types. The BTU content is specified as the lower heating value. This may, in part, explain the significant difference in the parameters for trash. Table 5 gives the six types of industrial waste produced in the Houston area.

TABLE 5
Wastes Classification

Type	*Description*	*% Moist*	*% Ash*	*LHV* (BTU/POUND)
I	Plant trash	6	10	7,500
II	Filter cake, sludges containing high moisture	50	30	12,000
III	Mixed solids	1	5	18,000
IV	High BTU Liquids	21	23	16,000
V	Polymers - Viscous when burning	5	5	17,000
VI	Difficult liquids, sludges and tars	50	6	12,000

The wide discrepancy between plant trash and trash in the Incinerator Institute standards cannot be accounted for. The difference may be regional but it is also possible the I.I.A. standard is obsolete.

As the operations of COPE moved into the design phase, it became evident that a supplementary designation for the required type of storage was necessary. A number of categories with letter designations was devised. For example, Storage Category G - Non-Viscous Low Ash Liquids covers primarily fuel oils which can be sorted in tanks.

Figure 3 is the current survey form used by COPE. Its ancestry from coal and oil analysis is obvious. As noted before, the term "tar" is misleading which is the reason for the additional data on liquids. It should be noted that this includes the viscosity index precluding any confusion.

COPE-INTERNATIONAL, INC.

Date: ______ Plant and Address ____________________

DESCRIPTION		*REMARKS*
Waste Designation	________	________
Quantity Tons/Mo	________	________
Density Lb/Cu.Ft.	________	________
Form (Solid, Liq., Tar, Semisolid)	________	________
Net BTU/lb Waste	________	________
Net BTU/lb Volatiles	________	________
% Moisture (as received)	________	________
% Ash (as received)	________	________
% Fixed Carbon (as received)	________	________
% Volatile (as received)	________	________
% Sulphur	________	________
% Halogen (indicate type)	________	________

Description and Chemical Composition, include pH:

Indicate corrosive, toxic, hazardous or difficult materials:

1. Transportation to be utilized:
   Truck ___ Barge ___
   Rail ___ Other ___
2. Schedule for deliveries:
   Daily ___ Weekly ___
   Bi-weekly ___ Monthly ___
   Intermittent ___

Additional Information for LIQUIDS:

% Fuel Oil ________
% Solids ________
Viscosity SSU ________

Temperature to produce a viscosity of:

100 SSU ________
50 SSU ________

Figure 3: Waste Characteristics

Returning to the arbitrary system of Figure 1, non-hazardous materials are divided into biodegradable and non-biodegradable. The non-biodegradable materials would be scrap metals, mill scale and similar wastes. While by-product gypsum is degradable under anaerobic conditions by sulfate splitting bacteria at fairly high temperatures, it is an unlikely circumstance. The biodegradable materials are mostly cellulosic-like garbage, paper and paper mill by-products. Hydrocarbons, especially straight chain paraffins, are readily decomposed. It is known that some petroleum refiners use a modified sanitary landfill method of disposal. Some plastics, such as unfilled polyethylene, are biodegradable under proper conditions.[5]

The biodegradable materials could be classified as hazardous since they are combustible, health hazardous and a hazard the NAS misses -

malodorous. The final division into combustible and non-combustible is also redundant. Custom and usage, however, dictates that these classifications be retained.

In summary, non-recoverable industrial solid waste may be broken down into two divisions — hazardous and non-hazardous. The hazardous wastes may be broken down into four classes — fire, health, water polluting and reactive hazards. Using the term "non-hazardous" in the context of the National Fire Protection Code, i.e. flammable materials with a relative high flash point are non-hazardous, we have two classes — biodegradable and non-biodegradable. Finally, there are two groups — combustible and non-combustible. This classification system is necessary for specific handling and storage procedures as well as disposal methods. For the purpose of incineration, it is suggested the type classification be retained. Types 5 and 6 of the I.I.A. standards should be appended to the COPE storage category classification. Thus, a waste fuel oil would be designated Type 7G if the COPE system is added to the I.I.A. standard. Additionally, because of the high flash point, it could be designated Division 2, non-hazardous. Its class would be biodegradable. The type number indicates that it is combustible.

There is ample material at hand for a rational classification system for solid wastes. The National Academy of Science System for classification of hazardous materials can be and should be applied to industrial solid wastes. Until the hazards have been fully evaluated, all studies and proposals for joint treatment of industrial and domestic wastes should be deferred.

REFERENCES

1. McConnaughey, Welsh, Lakey and Goldman. "Hazardous Materials Transportation." CEP 66, 2, February, 1970, p. 57-64.

2. Fulmer and Testin. "Report on the Role of Plastics in Solid Waste." Battelle Memorial Institute for the Society of the Plastics Industry, Inc. 1968.

3. "I.I.A. Incinerator Standards." Incinerator Institute of America. November, 1968.

4. Scher, J. A. "Characterization Techniques for Incineration of Organic Industrial Residues." The National Industrial Solid Wastes Management Conference, March, 1970.

5. Marchand, D. E. "Collection and Storage Systems for Non-Aqueous Liquid Wastes." The National Industrial Solid Wastes Management Conference, March, 1970.

6. Wooltolk, R. M. "Integrated Industrial Solid Wastes Processing Facility of COPE-Houston." The National Solid Wastes Management Conference, March, 1970.

7. Klee, Albert J. "Let DARE Make Your Solid Waste Decisions." The American City, 85, 2, February, 1970, p. 100-103.

8. Wessel, C. J. "Biodeterioration of Plastics." Society of Plastics Engineers Transactions 3 (4), 1964, p. 193-207.

Solid Waste Sampling Techniques

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In order to predict the character and behavior of solid waste materials it is necessary to determine with statistical reliability the exact chemical and physical composition of the waste materials. Solid waste materials are generally random in composition, and some parameters, such as moisture, extend over a wide range of values on a daily basis. Other changes in the composition, such as the percent of plastic matter, are occurring slowly, and the trends cannot be discerned over a short period of time. Many years, perhaps even a decade, will be required to show the change in composition of these minor components.

Previous Work

For purposes of analyzing a single sample or a series of small samples several researchers employed techniques which met the demands of the system being studied. Bell in his sampling of the City of Milwaukee used several cubic yards and quartered the refuse to a quantity of about one cubic yard.[1] The glass and metals were removed before the remaining wastes were shredded in a mill. By extracting the glass and metals the resulting sample could have been biased, for moisture and organic material are adsorbed on the surface of the inert matter. Removal of the organic material in the sample can change the overall characteristics of solid waste, especially with respect to odor.

Kaiser, in one study, used only a single sample of more than one cubic yard and separated the waste into fractions of paper, rags, metal, etc.[2] The choice of a large sample is necessary and desirable, but the unit cost of analyzing such a sample is prohibitive, and therefore this technique probably is not applicable to comprehensive studies, such as nationwide data gathering network.

Other techniques, including the Quad City study, used schemes for sampling, but the refinement of sampling methods is still being pursued.[3] All systems have some drawbacks either as to sample size needed or to sample accuracy.

In order to develop sampling procedures which are both statistically acceptable and yet not too costly, several schemes are given in this paper which were used to sample raw refuse and incinerator residue in the Philadelphia area.

Raw Refuse

Domestic refuse samples are taken to determine the chemical and physical properties of refuse which is charged to an incinerator or

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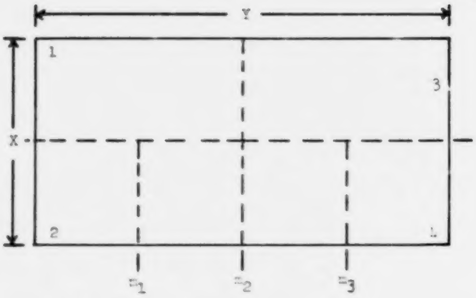
which is disposed of in a sanitary landfill. Domestic wastes are variable in composition, and their generation variables extend to all corners of the United States. A sampling procedure which is applicable to determine the character of the wastes throughout the United States is desirable. If it is assumed, as reported by Mix, that 800,000 tons of refuse are produced daily; and further assume that the average unit weight is 200 pounds per cubic yard, then the volume of wastes generated daily is eight million cubic yards.[4] To obtain a statistically representative sample of this large waste volume is almost impossible. If the sample size taken is only 0.1 percent, 800 tons of refuse must be sampled daily. These 800 tons must be taken randomly, and simply establishing an experiment to take random samples across the United States is uneconomical. If, as required by sampling theory, the collection of samples is random, the sampling teams may have to travel from city to city on a daily basis or have many teams located in different geographical areas. Assuming that sampling could be accomplished, the logistics of chemical analysis remain unsolved. Even if the samples are considered drawn from an infinite population, the accuracy of the results will not be known until after the sampling and analysis is completed.

The procedure presented for sampling of raw refuse was developed for use with either collection system sample or from an incinerator with an operation program as developed by the Public Health Service. The two techniques are slightly different, but both yield good results.

Collection System Sampling

To obtain samples from the collection system the sampling is done by randomly selecting the trucks used on the route. The number of trucks chosen will vary with the initial results of analysis. In order to check the sampling it is necessary to choose a parameter which can be used to predict the accuracy of the sampling. For large quantities of waste this can be a simple test such as the loss on ignition or the fraction which is soluble in organic solvent. Moisture content is not a good parameter, since there are too many external variables which affect the moisture content.

In order to sample from the trucks it is necessary that the trucks dump the load upon a flat surface, preferably concrete for simplified clean-up afterwards, and then take the samples from the piles as shown in Figure 1. To avoid the intermixing and placing on concentric circles, as proposed by the Quad City Study, it is required that the refuse be deposited upon the flat surface, and that the length and width of the pile be measured. When the pile is arranged as in Figure 1, samples are taken from the four corners as shown. From each corner a thirty pound sample is taken and placed either in a truck or in containers for future combining with the samples from the other locations. Figure 2 shows the vertical distribution of the waste, and where the thirty pound sample is collected in ten pound aliquots at each of three vertical sampling points. Samples at all four corners are collected in the same fashion.



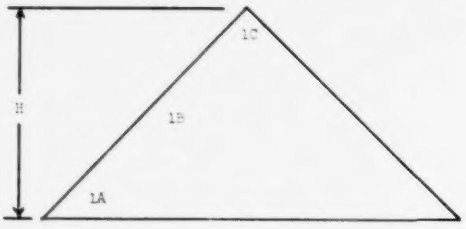
N = Total Number of Samples
M = Total along Horizontal Axis
M = (Y/X + 1)

Figure 1: Sampling Points from Residue or Refuse Pile — Plan View

In addition to sampling at the corners it is necessary to obtain samples from the center line of the pile. The number of center line samples is calculated by dividing the length of the pile by the width in feet plus one.

Refuse Sampling from an Incinerator

In the standard test procedure of the Public Health Service for determining the operating efficiency of incinerators, it is required that samples



No. 1 = (1A) + (1B) + (1C)

Figure 2: Sampling from Residue or Refuse Pile — Vertical End

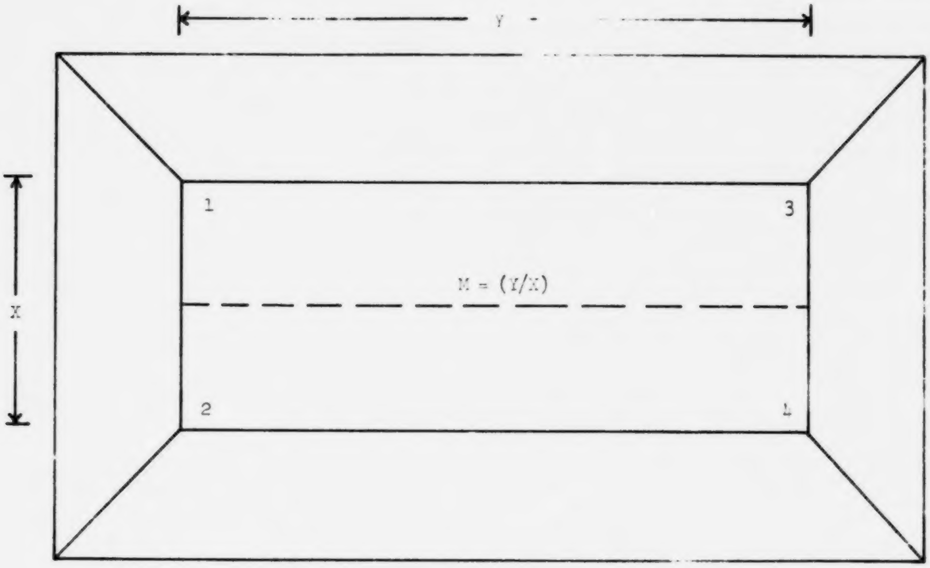

Y
X
1
3
2
4
M = (Y/X)
N = M + 4
N = Total Number of Samples
M = Number of Samples along Longest Axis

Figure 3: Sampling Points from Incinerator Hopper — Plan

of the refuse charged and residue discharged from the incinerator be collected and analyzed.

An open body is maneuvered into a position where it can be filled with refuse by the crane. The weight of refuse on the truck is determined by subtracting the vehicle tare weight from the gross vehicle weight. The crane is then used to charge the known refuse weight into the charging hopper. The charged refuse weight is determined by weighing the refuse remaining at the end of the test. For each crane bucket of refuse charged into the incinerator, a sample is taken at the charging hopper. One cubic foot is taken from each of the four corners, and one cubic foot samples are taken from the longitudinal axis as shown in Figure 3. All cubic foot samples are mixed together during grinding. Figure 3 shows all points of sampling from an incinerator charge hopper. Weighing the refuse before charging can be eliminated if only refuse samples are desired or if incinerator operation is not being monitored.

Residue Sampling

Sampling of incinerator residue is required when it is desired to analyze the residue produced under a given set of operating conditions. If the sample is to reflect residue character under a set of operating conditions, then the furnace retention time must be estimated. For example, at a design capacity of 12 tons per hour for a continuous feed incinerator, it requires several minutes for the refuse to reach the grate from the charging chute, and several minutes to traverse the combustion chamber. Thus, the sampling procedure must be offset to account for this retention time.

The sampling of residue in the proposed system is done on one truck of residue, since sampling directly from the discharge hopper is difficult and impractical. The trucks contain residue from a long period of operation, and generally contain a broader sample base than direct sampling. Sampling occurs generally after the residue is dumped on the ground. Individual samples are taken from each of the corners and at eight foot intervals along the longitudinal axis. Approximately 25 to 50 pounds of wet residue are taken at each sample point. Each point also includes vertical sampling as was shown in Figure 2. Thus, from each corner three samples are taken which are then consolidated into a single sample as was done on refuse sampling.

Sample Preparation

Before any analyses can be performed on either incinerator residue or raw refuse, the sample must be homogenized as much as possible and reduced in size. Homogenization can be partially achieved by reducing the particle size through grinding, shredding or crushing, followed by a thorough mixing of the sample. Unless some low boiling point components are vaporized during grinding the weight percentage between the constituents of the solid product should not be affected, but volume relationships will be destroyed.

The samples which were collected of raw refuse or incinerator residue are first pulverized in a general purpose hammermill. The mill should reduce the particle size through a combination of impact fracture and abrasion. After the entire sample is processed, it is thoroughly mixed, and then quartered until about one cubic foot remains. The remaining one cubic foot sample is again processed in a laboratory mill which further reduces the particle size to about a 3/16 inch maximum. This sample is now fully prepared for laboratory analysis.

Secondary Sampling

Secondary sampling is required to obtain from the sample of doubly ground material, an appropriate aliquot for each chemical analysis. Most of the techniques will require a sample of less than 50 grams. The method used to obtain the 50 gm aliquot is to split the sample by means of a riffler which divides the samples into aliquot portions through subsequent passes.

Special Sampling Problems

In sampling residue from an incinerator, care must be taken to perform the material balance on the residue as well as on the excess water used to quench the residue. This excess water leaches material from the residue, thereby subtracting that material from that discharged. Inorganic salts are particularly soluble, but organic matter is also removed. The organic matter plus the soluble salts must be added to the analysis of the residue.

Results of Sampling

Table 1 shows the results of the combustible fraction in incinerator residue and the two sampling techniques for unburned refuse. The various columns are related to the following statistics.

1. Number of Samples: The total number of samples which were drawn and analyzed. Each sample drawn was done in a random way. All samples were drawn in the City of Philadelphia over a period of two years.

2. Total Analyses: After secondary sampling, each sample drawn was replicated three to five times, and the number of replicates for all samples is the Total Analyses.

3. *Mean*: Percent combustible for all analyses including the replicates.

4. Standard Deviation Experimental: This is the standard deviation based on the internal variations in the multiple samples and does not include the components due to variations between samples. The internal variations could be considered as being due to experimental measurement variations as well as lack of homogeneity within the several samples. If the samples are considered to be homogeneous, then this can be considered as the variation due to the measuring technique.

5. Standard Deviation Total: This is the standard deviation based on the internal variation in the multiple samples as well as the variation between samples. This statistic treats the data as if it were one big sample and includes the experimental variation, as well as that due to the heterogenous nature of the sample and the day-to-day variations between samples.

6. Significant Difference Experimental: Differences based on the measurement system and

TABLE 1
Analytical Results of Sampling

	Residue No. 1	*Raw Refuse*	
		Collection	*Incinerator*
Percent — Mean Combustible	18.72	48.42	58.16
Number of Samples	43	14	18
Total Analyses	161	51	85
Standard Deviation Experimental	3.3	10.09	5.48
Standard Deviation Total	11.00	21.42	19.18
Significant Difference Experimental	4.09	12.51	6.80
Significant Difference Total	13.64	26.56	23.78
Significant Difference Among All Samples	yes	yes	yes

the heterogeneous nature of the samples as calculated on five replicate analyses are shown by this statistic. Any lesser differences could be due to random variation.

7. Significant Differences Total: This is the difference which one can expect to detect, based on the present measuring system, the heterogenous nature of the samples and the day-to-day variation and using a sample consisting of five analyses. Any lesser differences can be due to random variations.

8. Significant Difference Among All Samples: A value based on the standard analysis of variance where yes means that there was a significant difference among the various sample means based on the internal variation within the sample. *No* means that the data did not indicate that there was a significant difference; hence there is no reason to conclude that there is any difference among the sample means. In all cases the level of significance was 0.05, which means there is a 5 percent chance of making an error when it is concluded that the difference was significant. Where *no* is indicated it simply means that the actual differences which exist could be due to sampling variations or else our measuring variations are too great to detect an actual difference when it exists.

In the results shown in Table 1, the mean is significant for purposes other than estimating the applicability of the sampling and analytical system. The number of samples and the total analyses show that a total of 75 samples were taken, and almost 300 analyses were performed. It was necessary to use this large number of samples in order to get statistical validity.

In all cases the experimental standard deviation was less than the total standard deviation, which indicates that the error introduced by the analytical and sampling procedures is less than the total variation. The experimental significant difference shows that the secondary sampling is not giving homogeneous samples since the error is almost ± 20 percent. It does show that for any given sample of refuse or residue, the results of the analytical determination are probably the reflection of the values of that sample.

The final line of Table 1 states that there is a difference in character for the samples collected. This is not surprising in that it has been known for a long time that refuse is heterogenous, and there is a day-to-day variation in composition. Reasons for this day-to-day variation are attributed to the random nature with which samples are collected. No efforts were made to separate socio-economic effects, seasonal effects or demographic variation.

SUMMARY

Adequate sampling of refuse and residue is a laborious and costly part of any solid waste survey. To help reduce this cost the technique presented is designed to use less manpower than other methods previously used. One person could perform the sampling in about one-half hour. This means that more samples can be taken during any given period of time.

It must be emphasized that the sampling procedure is applicable only for chemical analysis of the refuse or residue. The sample taken is small compared to a compactor truck or a crane bucket used to charge an incinerator. It may be possible to use a manual separation method, but no data are available to either prove or disprove its validity.

LIST OF SYMBOLS

M = total number of samples along centerline of pile

Y = length of pile being sampled

X = width of pile being sampled

N = total number of samples = $M + 4$

REFERENCES

1. Bell, John M. "The Physical and Chemical Composition of Municipal Refuse," Purdue University, August 20, 1960.

2. Kaiser, E. R. "Chemical Analysis of Solid Waste," Proceedings of 1966 National Incinerator Conference. American Society of Mechanical Engineers, New York, 1966.

3. Ingram, William T. and Francia, Frank P. "Quad-City Solid Waste Project and Interim Report, June 1, 1966 to May 31, 1967. Government Printing Office, Washington, D. C.

4. Mix, S. A. "Solid Waste: Every Day Another 800 Million Pounds," *Today's Health*, Vol. 14, #6, 1966.

Characterization Techniques for Incineration of Organic Industrial Residues

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Classification systems for liquid, semi-liquid and solid waste systems have been available for many years. There are many ways to classify these wastes and below is an attempt to discuss some of them beginning with solid wastes and leading up to industrial organic residues.

The Incinerator Institute of America has established a classification system for wastes based partly on its content and partly on the BTU value and moisture present. The classification system is outlined below:

Type 0 — Trash: mostly paper, cardboard, wood, etc. This type of waste contains 10 percent moisture, 5 percent incombustible solids and a heating value of 8,500 BTU per pound.

Type 1 — Rubbish: paper, wood scrap, foliage, floor sweeping. This type of waste contains 25 percent moisture, 10 percent incombustible solids and has a heating value of 6,500 BTU per pound.

Type 2 — Refuse: an even mixture of rubbish and garbage. This waste contains up to 50 percent moisture, 7 percent incombustible solids and has a heating value of 4,300 BTU per pound.

Type 3 — Garbage: animal and vegetable wastes. This waste contains up to 70 percent moisture, up to 5 percent incombustible solids and has a heating value of 2,500 BTU per pound.

Type 4 — Pathological Waste: animal remains. This waste contains up to 85 percent moisture, 5 percent incombustible solids and a heating value of 1,000 BTU per pound.

Type 5 — Industrial gaseous, liquid, or semi-liquid residues.

Type 6 — Industrial solid wastes.

Types 5 and 6 wastes are very discreetly not defined by the Institute because of the wide variety in materials. All that is said is that the BTU value of each individual material must be determined. However, there is much more needed in a classification system for organic industrial wastes than BTU values in order to properly design and operate an effective incinerator. Some of these characterization techniques will be discussed in this paper. Several of the characterization procedures are based upon standard ASTM techniques for materials classification.

1. Waste designation—this classification may take the form of tank bottoms, spent phenol, acid sludge, etc. If the designation is thought to expose a confidential industrial process, then some sort of code system may be used. This classification is essential in grouping together like materials for ease of handling, storage and combustion.

2. Waste Type — a simple system has been devised to further break down the above type of description.

Type I — Mixed solid combustible materials such as paper and wood.

Type II — Pumpable, high heating value, moderately low ash, high moisture materials such as skimmer emulsion, tank bottoms, heavy ends.

Type III — Wet, semi-solids such as refuse and water treatment sludge.

Type IV — Uniform, solid burnables such as waste polymers.

Type V — Pumpable, high ash, low heating value materials such as acid or caustic sludges or sulfonates.

Type VI — Difficult or hazardous materials such as toxic compounds, hydrofluoric acid or pesticide residues.

Type VII — Other materials to be described in sufficient detail to classify accordingly. One might expect that Type VII would be a category used frequently in defining waste type because of the wide variety and inhomogeneity of industrial wastes. Again, this characterization technique is not based upon any scientific test, but rather upon visual observation and process designation.

3. Waste Form — This classification further elucidates the physical nature of the waste and its handling characteristics. One may define the following sub-classifications:

a. Solid-dry materials suitable for handling by front-end loader or buckets.

b. Semi-solid wet material suitable for handling by front-end loader or buckets.

c. Semi-solids — sticky or tarry substances not suitable for handling by front-end loader or buckets.

d. Mixtures of solids and liquids not suitable for handling by front-end loader.

e. Viscous liquids pumpable when hot or with special pumps.

f. Liquids suitable for normal pumping equipment.

g. Packages — materials to be handled in combustible boxes or cartons.

h. Drums — materials handled in 55 gallon steel drums.

4. Density — The bulk density of a material is normally given "as is," i.e., the condition received or stored. Density is normally defined as grams per cubic centimeter or more frequently as pounds per cubic feet. The density can range from 3 to 4 pounds per cubic feet for loose paper to over 60 for heavy liquids and sludges.

5. Net BTU per pound of waste — the caloric heating value of the particular waste is important for design purposes. BTU values are determined in a bomb calorimeter. Material is combusted and the heat released is measured by temperature rise after correction for ash and moisture. BTU values can range from one or two thousand per pound up to 60,000 per pound for hydrogen. Typical industrial wastes have heating values ranging from 5-20,000 BTU's per pound.

6. Moisture — the ASTM — Ds71 test defines moisture content as that waste driven off at 110°C for one hour. This temperature does not, of course, remove most combined water or water of hydration. This test is adequate for solid (or semi-solid materials) but is adequate for liquids. Moisture in liquid samples is measured by distilling the sample with an immiscible solvent such as benzene or toluene and measuring the water volume released.

7. Volatile material — heating the sample to 950°C for seven minutes in the absence of air to prevent loss by oxidation will drive off the volatile material. The moisture content must be subtracted from the volatile material. This temperature will volatilize most carbon, water of hydration and non-metallic compounds.

8. Fixed Carbon — some carbon, such as metallic carbides and other highly stable compounds, is not volatilized at 950°C. Because no oxygen is available, the fixed carbon will not react to form carbon monoxide or dioxide. The fixed carbon is generally considered as an entity separate from the ash and is calculated on a moisture free basis.

9. Ash — when the volatile material is driven off at 950°C in an oxidizing atmosphere, only the ash will remain. The fixed carbon will evolve as CO or CO_2 and only the inorganic, non-combustible residue will remain. The ash is the material that must be handled after incineration so its weight (or volume) is important. Ash is calculated on a moisture free basis.

10. Sulfur or halogens — both of these elemental groups are important because of their relationship to air pollution regulations. Of particular importance here are the oxides of sulfur, HC1, HF, chlorine gas and other fluorides which may evolve into the atmosphere. Sulfur and halogens can be determined titrametrically or gravimetrically from the ash or by elemental analysis.

11. Acidity — the pH of liquid or semi-liquid wastes is important in equipment design for material handling and combustion. Strong acid or basic wastes require special structural

materials or equipment. Also, it is important not to combine incompatible materials which might react chemically in storage or handling.

12. Viscosity — the viscosity of liquids or semiliquids changes rapidly with temperature. It is important to identify temperatures or conditions under which these materials may be transported easily by pumping. The viscosity can be measured by several methods including rotating disk and gravity flow viscometers.

13. Hazardous chemicals — there are many industrial wastes which contain chemicals which are extremely hazardous because they are explosive, radioactive, pyrophoric, or toxic. Toxicity could be present before and/or after combustion or could be created by chemical reactions between inoffensive compounds. Examples of some of the above types of materials are cyanides, polysulfides, metal alkyls, nitrates and other nitrogen-containing compounds, some heavy metal salts and pesticides. It is extremely important to characterize these types of materials so that they may be handled accordingly. This type of characterization is best performed by the plant from which the waste originates, and it often involves some very extensive analytical tests.

14. Miscellaneous analyses — there are some materials which might require special analyses or characterizations in order to further elucidate their behavior when in contact with certain compounds or when subjected to combustion. Examples of such materials are polymers. Some burn quickly with explosive force, some melt and then burn, others hardly burn at all. Many polymers contain functional groups in their structure which may be hazardous or dangerous in certain environments.

Instrumental tests such as gas chromatography, thin-layer chromatography, mass spectrometry, atomic absorption, infrared and ultraviolet spectrometry, elemental analysis and a host of other methodologies may be employed to completely characterize a waste in order that it may be handled and combusted with maximum care and efficiency.

Use of the fourteen groups of tests described in this paper will adequately characterize most industrial organic wastes so that they may be handled, blended and incinerated properly and safely.

Analysis of Refuse and Incinerator Residue

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and
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After sampling either refuse or incinerator residue materials the degree of analytical detail and the emphasis of desired tests must be made. Refuse and residue characteristics vary widely, and the analytical scheme chosen depends upon the use of the results. Table 1 is a summary for the reasons of characterizing refuse, and Table 2 is a like summary for incinerator residue.

Characterization rather than quality is chosen as the descriptive term because it is felt that the term quality is too restrictive. Quality implies that there exists a basis for comparison, when in fact, there are no such standards yet in existence.

Reasons for Characterization

As shown in Table 1, the primary reason for characterizing refuse is to ascertain its amenability to various forms of handling and treatment. For incineration, the heating value is one important parameter, while for sanitary landfill disposal, heating value is not needed. For composting, the carbon-nitrogen ratio is important for process control, but it is of little use in predicting combustion kinetics. Thus, depending upon the ultimate method of disposal, the analytical scheme will be tailor-made to suit the disposal evaluation needs.

TABLE 1
Characterization of Refuse

1. Disposal
   - a. Incineration
   - b. Composting
   - c. Landfill
   - d. Pyrolysis
2. Salvage
3. Recovery
4. Reuse
5. Find trends & Production
   - a. New Products
6. Prevention of Waste Generation

Another reason for refuse characterization is to define where wastes are generated. The first step for control in a solid waste management system is to find where control measures can be implemented that will have the greatest effect. One such point is where wastes are produced. Some generation points can be replaced by an alternate process which produces no wastes or produces a waste which can be more easily handled. One specific example is the current research in developing a biodegradable paper container.

An investigation to determine where waste generation can be altered would naturally involve salvage, reuse and recovery. Salvage is defined as the recycling of wastes for use as a raw material in a similar process. An example is the use of newspaper in the manufacture of paperboard. Reuse implies recycling of the discarded material without altering its form and composition. An example is the returnable glass bottle. Recovery implies a processing step to recycle the discarded material. An example is ceramic matter which can be used as a building aggregate after a sintering operation.[1] When recycling is considered all three aspects become important.

Incinerator residue characterization is concerned with predicting the effectiveness of the incinerator in consuming the burnable material found in refuse. Methods for estimating burnout have been developed by Schoenberger and Purdom[2] and use loss-on-ignition as the measuring parameter. Other important reasons for determining the character of residue are for predicting possible uses of the residue particularly in salvage and recovery. Separation of the ferrous metals from residue is often easier than from the raw refuse. Ferrous iron from residue will be free of organic matter and other contaminants.

TABLE 2

Characterization of Incinerator Residue

1. Incinerator Effectiveness
2. Disposal
3. Residue Use
4. Salvage and Recovery

Not all incinerator residues have the same character; in fact, the degree of burnout significantly alters the physical and chemical properties of residue. Residue which results from poorly burned refuse will have paper and food wastes visible. This type of residue requires disposal by sanitary landfilling or by further incineration. Residue which results from completely burned refuse has a greyish hue, and no unburned organic material is visible. While not a valid method of characterizing residue, color does indicate the amount of burnout. The poorly burned residue is multicolored (unburned material) against a black background. The next step in burnout is the disappearance of the multicolor leaving a black background of char and unburned carbon. When the char is burned, the residue is greyish. While there may still be burnable matter as determined by loss-on-ignition, for even the grey residue, the combustible fraction is related mostly to the burning of free carbon, and it is not usable as a foot source and will not produce odors or attract biological vectors.

Somewhere between the refuse charged and completely inert (non-combustible) residue lies all incinerator residues produced in the United States, with the possible exception of experimental units. Figure 1 shows the relationships which exist between refuse as charged to an incinerator and the residue discharged from the combustion zone. Material can be divided into combustible (V_0) and non-combustible (A_0) where the sum of these two fractions is equal the total weight of refuse charged on a dry basis. The residue discharged has a combustible fraction (V_f) and a non-combustible fraction (A_f). The relationship between the refuse and residue is given by the fraction (A_0') and (V_0'), which are the combustible and non-combustible fraction of residue which results from burning one unit weight of refuse. The percent of burnout is $(K/V_0)100$.

During the burning of refuse, the wastes are thermally destroyed, and metals and salts which are bound to the organic matrix are released and become part of the non-combustible (A_0) fraction. Many of these materials, e.g., calcium, sodium and potassium, are soluble in water and pose a potential pollution problem when the residue is used for land reclamation or as a building material. This fraction of salts is not readily soluble in unprocessed solid waste.

Figure 2 is a flow chart of the analytical scheme developed at Drexel University for characterizing either raw refuse or incinerator residue. The entire analytical scheme need not be followed on every sample, but if a detailed chemical characterization of either refuse or residue is required, the procedures are available.

Analytical Methods

After the sample is taken, moisture content should be determined before size reduction. During size reduction the material is air elutriated which results in a moisture loss, and the energy input of the mechanical systems results in a moisture loss. The temperature of the metal fraction is raised through cold working, and moisture adsorbed on the metal surface is evaporated. The rest of the sampling system is as described elsewhere by Schoenberger and Purdom.[3]

The analytical scheme was developed to utilize basic test procedures, e.g., the combustible and non-combustible fractions, and to expand the analysis as a fraction of these two major parts. The simplest expansion involves the non-combustible fraction where organic matter and metals are removed by digestion in aqua regia. The remaining solids are dried and ignited in a muffle furnace where elemental carbon, the major combustible fraction remaining, is oxidized to carbon dioxide, leaving only a nonacid soluble ash which is primarily silica.

Other individual tests also are necessary to analyze the non-combustible fraction. These include determination of iron, aluminum, zinc and copper.

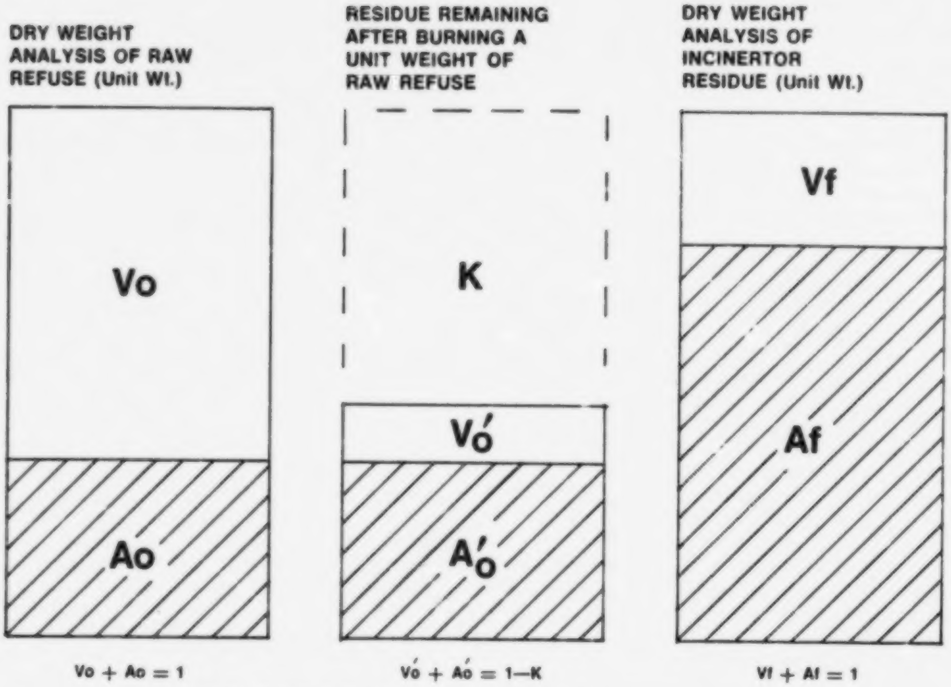
DRY WEIGHT ANALYSIS OF RAW REFUSE (Unit Wt.)
RESIDUE REMAINING AFTER BURNING A UNIT WEIGHT OF RAW REFUSE
DRY WEIGHT ANALYSIS OF INCINERTOR RESIDUE (Unit Wt.)
Vo
Ao
K
Vo′
Ao′
Vf
Af
Vo + Ao = 1
Vo′ + Ao′ = 1—K
Vf + Af = 1

Figure 1: The Relationship Between Unburned Refuse and Incinerator Residue

During expansion of the combustible fraction analysis carbon, hydrogen and cellulose are taken as the first breakdown of that fraction. Since paper is such a large part of the total quantity of solid waste, carbon and hydrogen ratios will reflect the paper fraction.

Extraction of solid wastes with water and organic solvents gives an estimate of the biochemically degradable fraction, and the fraction which could cause immediate water pollution. The organic solvent extractables include fats, greases, waxes, volatile acids and other biochemical degradation products of the food wastes. Speciality tests may be performed on the organic soluble fraction, and recommended tests include organic nitrogen, carbohydrate, protein and a solids analysis. The protein and carbohydrate fractions are important, since they serve as food and nutrient sources for vectors when they are placed on the open land. It is these materials which attract flies, rats and birds, and which is the source of food for these nuisances.

The water soluble fraction is a combination of both organic and inorganic materials which can be backed with water. The inorganic materials are mostly soluble salts which are released during the burning of the combustible fraction, and they are primarily alkaline metals and salts of alkaline earth metals.

Figure 3 is a diagram showing the analysis of the water soluble fraction. This fraction includes mostly the inorganic salts which are limited by discharge standards to surface streams or which may upset municipal sewage treatment facilities.

Special Chemical Techniques

In following the detailed analytical scheme of Figure 2, quantitative methods for analysis must be carefully chosen. Incinerator residue analysis and in particular the water soluble fraction are subject to many interferences which result from interaction between the various constituents. Few wet chemical techniques have been found useful, and in particular colorimetric methods have been shown to be of doubtful accuracy. Many ionized substances are complexed with other ions present, thus putting greater emphasis on the selection of reliable analytical techniques.

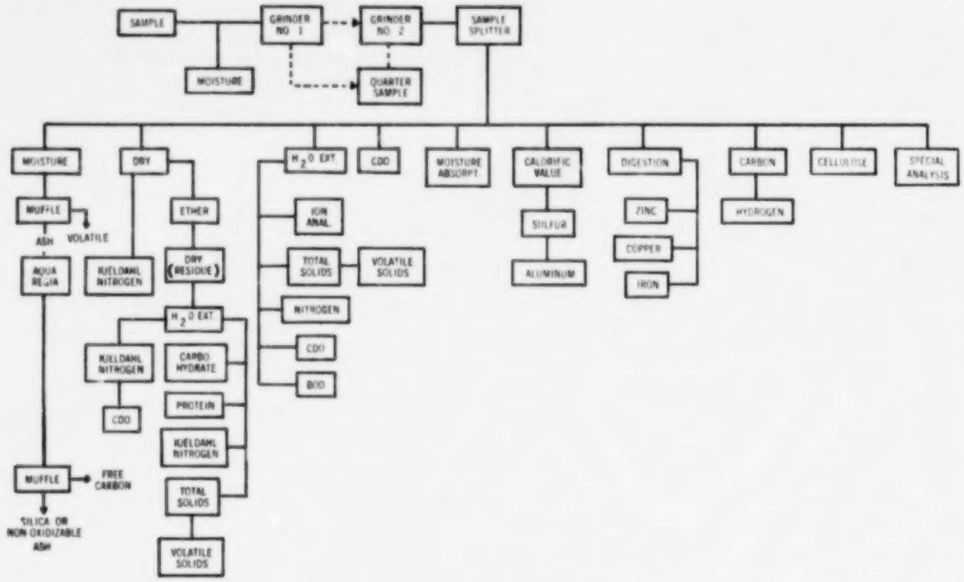
SAMPLE
GRINDER NO 1
GRINDER NO 2
SAMPLE SPLITTER
MOISTURE
QUARTER SAMPLE
MOISTURE
DRY
H_2O EXT
COD
MOISTURE ABSORPT
CALORIFIC VALUE
DIGESTION
CARBON
CELLULOSE
SPECIAL ANALYSIS
MUFFLE
VOLATILE
ASH
AQUA REGIA
KJELDAHL NITROGEN
ETHER
DRY (RESIDUE)
H_2O EXT
KJELDAHL NITROGEN
CARBO HYDRATE
PROTEIN
KJELDAHL NITROGEN
TOTAL SOLIDS
VOLATILE SOLIDS
COD
MUFFLE
FREE CARBON
SILICA OR NON OXIDIZABLE ASH
ION ANAL
TOTAL SOLIDS
VOLATILE SOLIDS
NITROGEN
COD
BOD
SULFUR
ALUMINUM
ZINC
COPPER
IRON
HYDROGEN

Figure 2: Solid Waste Analysis Flow Chart

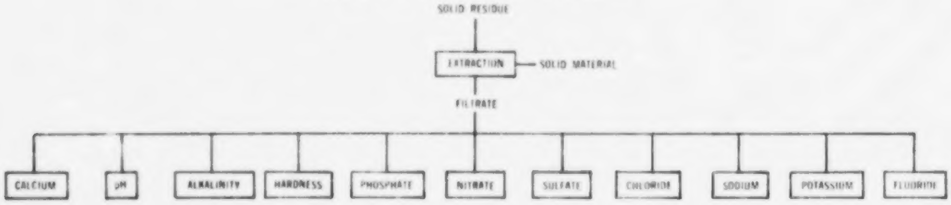
SOLID RESIDUE
EXTRACTION
SOLID MATERIAL
FILTRATE
CALCIUM
pH
ALKALINITY
HARDNESS
PHOSPHATE
NITRATE
SULFATE
CHLORIDE
SODIUM
POTASSIUM
FLUORIDE

Figure 3 Analysis of Water Soluble Fraction

The accuracy of chemical techniques used in analyzing incinerator residue are constantly being upgraded. In the case of metals, atomic absorption techniques are being developed which will replace the traditional standard methods. With proper preparation methods, atomic absorption does reduce the analytical error.

Results of Analysis

Studies in the City of Philadelphia showed that only about 60-70 percent of all refuse is combustible. Of this total an average of 85-90 percent is thermally oxidized, leaving a sizable fraction of unburned material in the residue. For a good burnout this material will only be elemental carbon.

For each 100 pounds of residue (dry weight), there is a 5 percent fraction which is soluble in water. This fraction is predominantly metallic salts, and typical analysis show iron concentration of 5-10 mg/1, chloride - 500 mg/1, phosphate - 15 mg/1, nitrate - 10 mg/1, calcium 200 mg/1 and fluoride 4 mg/1. These results are based upon extraction of 250 grams of residue in two liters of solvent. It is this fraction which will be leached from residue deposited upon the land.

In the case of the fraction soluble in an organic solvent, its quantity is quite similar to the water soluble fraction until the burnout exceeds 90 percent. At this point the organic fraction decreases while the water soluble fraction remains the same.

CONCLUSIONS

The analysis and characterization of raw refuse or incinerator residue is dependent upon the use which is derived from the data. When further treatment is contemplated, as in composting or pyrolysis, the chemical data needed is different from that needed for sanitary landfilling or simply to determine what is the character of the waste.

The scope of the sampling system can be as large as one wishes to make the system. Certainly one of the most important functions of analyzing refuse or residue is to see if water pollution is imminent or whether there is no reason for engineering precautions in the system. The entire scheme is based upon chemical techniques, for it is believed that most of the major parameters are best measured by a chemical system.

At the present time little work has been done on some parameters such as the time of repose for residue or refuse. This parameter is critical in developing a feed or handling system. Other physical characteristics have also been neglected in describing refuse or residue.

BIBLIOGRAPHY

1. Franklin Institute, personal correspondence with Peter Morgan.

2. Schoenberger, R. J., Purdom, P. W. "Residue Characterization" J. San. Eng. Division, ASCE, June 1969.

3. Schoenberger, R. J. & Purdom, P. W. "Sampling Techniques for Raw Refuse and Incinerator Residue", Presented at 1970 National Conference on Industrial Solid Waste Management, Houston, Texas.

Characterization Techniques for Urban Solid Wastes

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To a person entering the field of solid waste management, two facts are immediately apparent:

1. There is a superabundance of solid waste material to be managed, and
2. There is a serious lack of factual data that can be used to characterize this material.

One of the most important factors necessary for systematic planning and improvement of existing and development of new solid waste management practices is "the development of adequate and reliable data related to quantity and composition of solid waste production."[1] This was identified as the second highest ranking research need of the solid waste management field at a 1966 American Public Works Association sponsored symposium.

One of the frustrations associated with the evaluation of a community's solid waste management practices and the recommendation for future actions is that the quantities of solid waste to be dealt with are too often based on either estimates or sample weighings over a limited period of time. In an effort to fill this recognized void, the United States Public Health Service (USPHS) Bureau of Solid Waste Management conducted the National Solid Wastes Survey in 1968 to develop information about community solid waste practices.[2,3] This is the most extensive survey of its type ever conducted with data collected from 6259 communities with a total population of 92,500,000, or 46 percent of the population of the United States. Despite the extent of this survey, less than 40 percent of the quantity data presented in the report as household waste is based on actual weighings; less than 20 percent of the combined household-commercial quantities reported were actual weighings.

Lack of factual data regarding the composition of municipal solid waste is in even shorter supply than quantity data. One of the factors that has caused the lack of reliable data on composition of solid wastes and is hindering efforts to develop the desired information is the lack of standardized procedures for sampling and analysis. The field of municipal solid waste management is in need of an established set of standard procedures of sampling and analysis with which to characterize solid wastes for use in design, operation, and environmental control of collection, storage, transport, processing, and disposal systems and, as emphasized at this meeting, recycling systems. Analogous standard procedures have been developed and have proven essential in the management of other areas of environmental pollution and control (e.g., *Standard Methods for the Examination of Water and Wastewater*).[4] The establishment of such standard test procedures would improve the overall effort toward adequate solid waste management for it would provide a uniform base for the dissemination and comparison of data. It would provide communities or waste disposal utilities with a standard set of procedures with which they could determine which method of disposal or recycling system would be appropriate to their waste problem and to identify the efficiency of their disposal method.

The USPHS Bureau of Solid Waste Management awarded a research grant to the Department of Environmental Engineering, University of Florida, with the objective of the development of standard test procedures for the examination of municipal solid wastes. The specific aims of this project in the accomplishment of the objective are fourfold:

1. The identification of the procedures and analytical methods presently being used in the characterization of municipal solid wastes for the design and operation of processing and disposal facilities and the evaluation of environmental pollution effects;
2. The evaluation of existing procedures and analytical methods on the basis of their appropriateness, precision and accuracy;
3. The identification of existing shortcomings, and recommendation of improvements to existing methods or development of new test procedures; and
4. The promotion of the establishment of an advisory committee on test procedures for municipal solid wastes, consisting of representatives of the USPHS Bureau of Solid Waste Management and the technical associations and societies concerned with solid waste management.

In accordance with the first aim of this project, an extensive literature search of the solid waste field is being conducted. State and area agencies designated with the responsibility of solid waste management planning and active researchers in the solid waste field are being canvassed to determine what test procedures are being used and to identify areas where methods of analyses need to be developed.

The responses to our questionnaire survey of state and area solid waste planning agencies indicate that almost all activities at this time are concentrated in surveys of operation practices and in development of quantity data; very little effort is being directed toward determining compositional characteristics of solid wastes. The establishment of procedures of identification of characteristics of leachate and incinerator residue were the most frequently cited needs.

A survey of active researchers in the solid waste field indicates that analyses from a variety of sources are being employed. The references cited are *Standard Methods for the Examination of Water and Waste-Water*, American Society of Testing Materials (ASTM) Standards,[5] *Official Methods of Analysis of the Association of Official Analytical Chemists*,[6] and the compilation of methods in Appendix A of *Municipal Refuse Disposal*.[7]

Recognition of the need for a "Standard Methods" for the examination of municipal solid wastes is not new. A research project entitled "The Physical and Chemical Composition of Municipal Refuse," sponsored by the National Institutes of Health, was conducted at Purdue University from 1957 to 1963. Dr. John M. Bell's doctoral dissertation, *Development of a Method for Sampling and Analyzing Refuse*, Purdue University, 1963,[8] presented a compilation of laboratory analytical procedures that would be basic to the design of methods of solid waste disposal.

The methods of analyses proposed by Dr. Bell plus analyses employed by John Wiley in his extensive work in evaluation of compost have been compiled and appear as Appendix A, "Tentative Methods of Analysis of Refuse and Compost," of *Municipal Refuse Disposal*, published by the American Public Works Association. This compilation of methods informally serves as a standard reference for analytical procedures for the examination of solid waste material.

Intramural forces of the Division of Research and Development, Bureau of Solid Waste Management, have been very active in the evaluation of physical and chemical parameters for characterization of solid wastes. The methods of analyses published in *Municipal Refuse Disposal* are presented without discussion as to their sensitivity, precision and accuracy. The laboratory staff of the Division of Research and Development, Bureau of Solid Waste Management, has initiated studies to evaluate the sensitivity, precision and accuracy of methods of analyses for eight selected parameters whose significance could be evaluated. These parameters are:

BOD of incinerator quench water
Carbon
Hydrogen
Nitrogen
Moisture
Ash
Volatile content
Calorific content

Methods of determination for the first four of these parameters have been established, and work is in progress on the other parameters.

Very recently another landmark study in the area of characterization of solid waste materials has been conducted. Drs. Schoenberger and Purdom have directed their research efforts to the development of "a system of analyses which can be used to determine the character of incinerator residue and raw refuse."[9] The analyses would then be employed to "evaluate the potential environmental interaction of refuse and residue" and to evaluate the efficiency of operation of incinerators and incinerator design.

The following parameters were suggested by Dr. Schoenberger for characterization of solid wastes:

Carbon
Hydrogen
Nitrogen (Organic)
Phosphate
Iron
Sulfur
Chemically Decomposable Organic
Water Soluble
Petroleum Ether Soluble
Heating Value
Ash
Combustible
Carbohydrate
Protein
Free Carbon
Silica

Dr. Schoenberger further suggested the following analyses to be performed on the water soluble fraction:

pH
Alkalinity
Hardness
Calcium
Iron
Sulfate
Chloride
Sodium
Potassium
COD
Nitrate
Phosphate
Fluoride

Methods of analyses for these parameters were evaluated by Dr. Schoenberger, and these analytical procedures are published in his Ph.D. thesis entitled *Characterization of Refuse and Incinerator Residue According to Potential Environmental Interaction and Incinerator Performance*, Drexel Institute of Technology, 1969.[9]

Interest in the development of standardized test procedures for analysis of solid wastes is not confined to the United States. The World Health Organization (WHO) Reference Center for Wastes Disposal in Zurich, Switzerland, has instituted a project to review and evaluate existing methods of solid waste sampling and analysis. They have just recently published a collection of methods to be used as a basis for discussion. A meeting on methods of sampling and analysis of solid wastes is proposed by WHO for 1971 or 1972.

Integral with the problem of developing analytical techniques for the characterization of solid wastes is the problem of sampling and sample preparation. The extreme heterogeneity in size and type of material comprising municipal solid waste presents severe difficulties in obtaining representative samples. Many elaborate quartering techniques have been used to obtain a representative sample of manageable proportions from a refuse truck containing about four tons of material. An example of such an elaborate procedure is detailed in the *Quad City Solid Wastes Project Interim Report*, June, 1, 1966, to May 31, 1967.[10]

The Bureau of Solid Waste Management Division of Technical Operations has conducted extensive studies on classification of wastes into categories and has made recommendations concerning optimum weight and number of samples necessary to validly determine solid waste composition.

Upon obtaining a representative sample, a series of category separation, grinding, mixing and subsampling steps must be performed to reduce the initial sample size to the size employed in the analytical procedure. The tentative methods presented in *Municipal Refuse Disposal* call for sizes of sample on which analyses are conducted ranging from 25 mg to 25 g. The reduction of the initial sample from its size of several hundred pounds to the weights called for in analyses (a 100,000 fold reduction) provides much opportunity for introduction of error into the result.

Two possibilities exist for alleviating this problem. One is the establishment of sampling and sample preparation procedures which eliminate or reduce the possibility for error. The other is the development of "macro" techniques of analyses to replace the present "micro" techniques that have been borrowed from other disciplines. This latter point was proposed by Dr. Andrew W. Briedenbach, Director of Research and Development, Bureau of Solid Waste Management, at the Engineering Foundation Research Conference on Solid Waste Research and Development, II, July, 1968. Macro-techniques of analyses may be developed which, although less precise than existing micro-techniques, are more accurate than the micro-techniques.

At the time of Dr. Bell's initial literature review in 1957 he noted a "surprisingly meager" knowledge of physical and chemical composition of refuse and the lack of any standard techniques for sampling or analyses. Since his work, and notably recently, there has been greatly increased activity in the area of solid waste characterization. The introduction to the tentative methods in *Municipal Refuse Disposal* contains the statement: "It is hoped that careful use and evaluation of the tests will lead to the adoption of more uniform and efficient methods of solid waste analysis."

Dr. Schoenberger closes his doctoral dissertation with the following statement:

"A search for the characterization of residue must continue. This dissertation is the first approach at attempting any characterization of residue according to potential environmental interaction. Future studies will undoubtedly refine the techniques proposed in this dissertation and will include a greater number of parameters. Whatever direction or approach is taken by future investigators, it is hoped that the foundation laid in this dissertation will be useful to anyone who accepts the challenge of residue characterization."[9]

Thus the base has been laid. It is necessary to coordinate the work of Bell and Schoenberger and others into a form available to all in the solid waste management field. There is general recognition of the need for a standardized set of procedures for examination of solid wastes. One of the stumbling blocks in the path of development of such a set of procedures is that there is no single unifying association or society that represents all of the factions in the field of solid waste management. Thus there is a need for the establishment of a joint committee of representatives of the various technical associations and societies such as: American Public Works Association, American Society of Civil Engineers (ASCE), American Society of Mechanical Engineers (ASME), American Institute of Chemical Engineers (AIChE), and American Public Health Association (APHA). With the addition of representation from the USPHS Bureau of Solid Waste Management this committee would span the broad scope of the solid waste management field. This committee would provide the broad base for direction in standardization of test procedures and dissemination of information through the constituent organizations. This would be a giant step in the unification of effort toward the efficient management of municipal solid wastes.

REFERENCE

1. American Public Works Association. *Solid Wastes in Perspective: Proceedings of a Symposium on Research Needs.* Philadelphia, Pennsylvania, January 28-29, 1966.

2. Black, R. J., Muhich, A. J., Klee, A. J., Hickman, H. L., Jr., and Vaughan, R. D. *The National Solid Wastes Survey; an Interim Report.* U.S. Department of Health, Education, and Welfare. Cincinnati, Ohio, 1968.

3. Muhich, A. J., Klee, A. J., and Britton, P. W. *Preliminary Data Analysis; 1968 National Survey of Community Solid Waste Practices.* Public Health Service Publication No. 1867. U.S. Government Printing Office, Washington, D. C. 1968.

4. American Public Health Association. *Standard Methods for the Examination of Water and Wastewater*, 12th Edition. New York, 1965.

5. American Society for Testing Materials. *Standard Methods of Laboratory Sampling and Analysis of Coal and Coke.* ASTM Designation: D271-64.

6. Association of Official Analytical Chemists. *Official Methods of Analysis*, 10th Edition. Washington, D. C. 1965.

7. American Public Works Association. *Municipal Refuse Disposal*, 2nd Edition. Appendix A: Tentative Methods of Analysis of Refuse and Compost. Chicago, Illinois, 1966, p. 375-399.

8. Bell, J. M. *Development of a Method for Sampling and Analyzing Refuse.* Ph.D. Thesis, Purdue University, 1963.

9. Schoenberger, R. J. *Characterization of Refuse and Incinerator Residue According to Potential Environmental Interaction and Incinerator Performance*, Ph.D. Thesis, Drexel Institute of Technology, 1969.

10. Ingram, W. T., and Francia, F. P. *Quad-City Solid Wastes Project; An Interim Report, June 1, 1966 to May 31, 1967.* U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, 1968, p. 2-2 to 2-9.

TENTATIVE METHODS OF ANALYSIS OF REFUSE AND COMPOST

Appendix A of *Municipal Refuse Disposal*[7]

Moisture (Water)
  Over Drying Method
  Infrared Method
  Toluene Distillation Method

Volatile Solids and Ash

Lipids (Ether Extract)

Liquids

Crude Fiber

Sugars

Starch
  Anthrone-Sulfuric Acid Method
  Direct Acid Hydrolysis Method

Carbon

Nitrogen (Organic and Ammoniacal)
  Kjeldahl-Wilfarth-Gunning Method

Protein

Carbon-Nitrogen Ratio

Phosphorus (Phosphate)

Potassium (Potash)
  Flame Photometric Method
  Sodium Tetraphenyl Borate Method

Hydrogen-Ion Concentration (pH)

Gross Calorific Value

Net Calorific Value

Sulfur

Hydrogen and Carbon

Pyrolysis of Polyvinyl Chloride

DR. MICHAEL M. O'MARA
B. F. Goodrich Chemical Co.

INTRODUCTION

The technique of pyrolysis has been applied by chemists for years to gain basic knowledge of the thermal stability and degradation mechanisms of organic compounds. The innovation of gas chromatography has resulted in the coupling of gas chromatography and pyrolysis to provide a powerful analytical tool, especially for the polymer chemist. The application of pyrolysis-gas chromatography (PGC) to problems involving polymer stability, mechanism of thermal breakdown and polymer characterization has been well described in the literature.[1] General aspects of the technique[2,3,4,5] and its use on a wide variety of problems[6] have also been discussed.

The increasing use of plastics in today's society requires that consideration be given to changes in present disposal procedures ranging from those of municipal incineration to the disposal of industrial waste. The effects of plastics in municipal waste and incineration has been dealt with in the past[7,8,9] and is currently being restudied.[10] The problems of industrial waste are by nature more diversified and are dependent upon the specific material being produced. However, the technique of pyrolysis coupled with various analytical tools offers a method of studying problems involving the flammability, disposal and characterization of plastics. For example, the flammability of polymers has gained considerable attention in the past years. Work by Fenimore[11,12] and others[13] has shown that most polymeric materials burn by a candle-type mechanism. In other words, once ignition takes place, the heat generated from the exothermic combustion reaction causes the polymer to thermally degrade with the production of pyrolysis products. These gases mix with ambient air and further combustion takes place. Based on this model, pyrolysis-gas chromatography affords a technique by which the primary pyrolysis products from a polymer can be generated and measured.

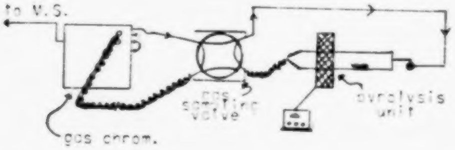
The use of pyrolysis in the area of waste disposal is of importance from two aspects. With the increasing concentration of plastics in municipal waste, PGC is invaluable with respect to its characterizing or fingerprinting capabilities. In addition, since the flammability of most plastics is a function of the pyrolysis products, the efficiency of combustion can be determined through a quantitative and qualitative analysis of the pyrolysis products. Current trends in reclamation of waste and reclamation of the thermal degradation products of waste are another aspect of the utility of PGC.

This paper deals with the use of PGC as an analytical tool for characterizing polyvinyl chloride (PVC) homopolymer, copolymers and compounds. In addition, the application of PGC to the disposability of waste PVC and chlorinated PVC from a standpoint of reclamation will also be discussed. (See Figure 2 for polymer identifications.

Instrumentation

The pyrolysis unit used throughout this work consists of a quartz tube, radiant heat pyrolyzer and flow lines into and out of the system. The pyrolysis unit is interfaced to a F & M Model 700 gas chromatograph through a F & M gas sampling valve. This valve and all effluent lines are heated to 150°C during pyrolysis experiments. The gas chromatographic carrier gas lines have been extended to the outside body of the instrument through Tygon tubing connectors. In this way, either one of the injection ports on the chromatograph can be used. The gas chromatograph and mass spectrometer (CEC 21-103C) interface consists of a Biemann separator.[14]

Additional information and a graphic illustration of the apparatus are provided in Figure 1.



PYROLYSIS UNIT: 23cc. , 1000°C.

GAS CHROM.: F&M MODEL 700,THERMAL
CONDUCTIVITY,HELIUM

MASS SPECT.: CEC21-103C

PGM INTERFACE: GAS SAMPLING VALVE
G.C.-M.S. " : BIEMANN SEPERATOR

Figure 1: Pyrometer-Gas Chromatograph

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Pyrolysis of Polyvinyl Chloride (PVC)

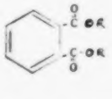
A pyrogram of PVC is shown in Figure 3. This was obtained by pyrolyzing ~10 mg of PVC homopolymer at 600°C in a helium atmosphere. Under these conditions, a stoichiometric release of chlorine as hydrogen chloride is realized. In addition, a series of aromatic, aliphatic and olefinic hydrocarbons are also obtained. Compound identifications were made through mass spectrometric analyses. A complete analysis of the pyrolytic products is contained in Figure 4.

POLYVINYL CHLORIDE

~CH-CHCl-CH-CHCl~

PLASTICIZED POLYVINYL CHLORIDE

~CH-CHCl-CH-CHCl~



CHLORINATED POLYVINYL CHLORIDE

~CHCl-CHCl-CHCl-CHCl~

Figure 2: Polymer Identifications

The major component of this hydrocarbon fraction is benzene; the entire fraction consists of mainly aromatic hydrocarbons, with minor amounts of aliphatic and olefinic compounds. Only one chlorinated hydrocarbon was found in the hydrocarbon fraction and the level of this was quite low.

Assuming that PVC burns via a candle type mechanism, incomplete combustion of this polymer should produce benzene as the major organic product in the combustion gases. A recent study of the volatile combustion products from PVC indicates that the major organic product in the combustion gases is benzene.[15] In addition, phosgene could not be detected (0.1 ppm) in the combustion gases from PVC.

Basic pyrolysis experiments indicate that thermal degradation methods may be an approach to the reclamation of hydrochloric acid (~58 percent of the polymer) from waste PVC. Additional pyrolysis information shows, however, that the hydrocarbon fraction from PVC is so small and the product distribution so varied that reclamation of this hydrocarbon fraction would not be feasible.

It should be pointed out that while the reclamation of HCl in an incinerator-boiler system may be feasible, and even look attractive on a laboratory scale, much work remains to be done to establish this method. For example, the quality of the recovered HCl from such a recovery process may pose some severe limitations on its end use since it must compete in the market place with low cost, high purity acid.

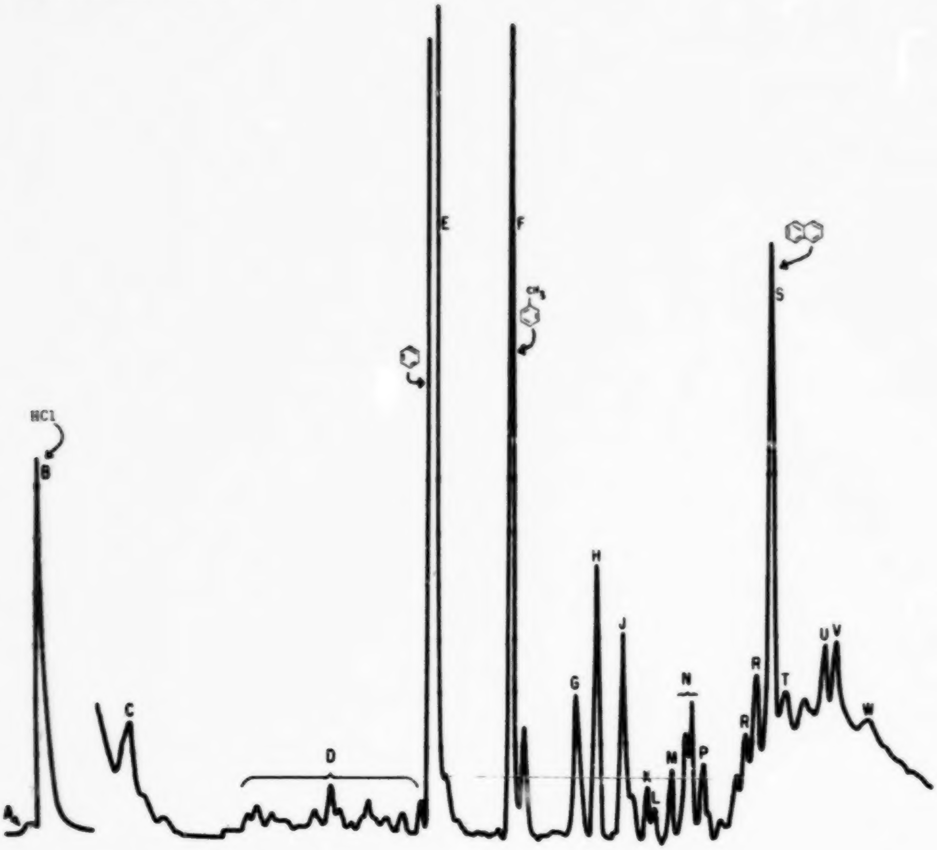


Figure 3: Pyrogram of Polyvinyl Chloride

It is then evident that any scheme that may be proposed for the recovery of useful materials from solid waste presents a concomitant problem of market development, and often times these markets are outside of the current sphere of interest of the industry involved.

Pyrolysis of Plasticized PVC

Many commercial applications of PVC call for the use of a plasticizer which renders the polymer soft and pliable. Typically phthalate, phosphate, adipate, azealate and other esters are fused with the PVC homopolymer to give a soft pliable plastic.

Pyrolysis of a PVC-di (2-ethyl hexyl) phthalate plastisol at 600°C results in the formation of a pyrolyzate that reflects polymer and plasticizer degradation. The amount of HCl released from this matrix is less than that released from a pure homopolymer due to the dilution effect of the plasticizer. It should be noted that the decreased quantity of HCl released from the plastisol is due only to a dilution effect. There is no evidence of the evolved HCl undergoing secondary reactions with the organic portion of the effluent.

Besides HCl, the pyrolyzate contains an organic fraction which consists of benzene and other aromatics from the PVC and phthalic anhydride and 2-ethyl hexenes from the plasticizer (see Figure 6). An overall degradation profile and an analysis of the hydrocarbon portion of the pyrolyzate is summarized in Figure 5. To illustrate the characterizing or "fingerprinting" capabilities of pyrolysis-gas chromatography, a series of plastisols containing differ-

OVERALL DEGRADATION PROFILE

	%
HCl	58.3
HYDROCARBON FRACTION	37.0
CARBON CHAR	4.7

DEGRADATION PROD.	1	2	3
CO	0.6	2.2	0.8
METHANE	8.8	7.5	9.3
CARBON DIOXIDE	0.4	0.3	0.2
ETHYLENE	3.5	3.5	3.8
ETHANE	4.8	5.2	5.5
PROPYLENE	2.9	2.6	3.0
PROPANE	3.0	1.9	2.3
C/4 HYDROCARBONS	2.5	2.1	2.1
C/5&C/6 "	1.9	1.8	1.3
BENZENE	51.2	50.8	50.1
TOLUENE	5.3	5.9	5.8
CHLOROBENZENE	1.1	1.1	1.3
XYLENE	1.9	2.1	2.3
ALLYLBENZENE	1.3	1.4	1.6
C_9H_{12}	1.3	1.4	1.6
"	0.2	0.2	0.3
INDANE	0.2	0.3	0.3
INDENE ETHYLTOLUENE	0.9	1.4	0.9
METHYLINDENE	1.1	1.3	1.0
NAPHTHALENE	4.8	4.6	4.5
DIMETHYLINDANE	0.7	0.8	0.8
METHYLNAPHTHALENE	0.8	0.7	0.7
" ACENAPHTHALENE	1.2	1.0	1.1

Figure 4: Analysis of Pyrolytic Products

OVERALL DEGRADATION PROFILE

	%
HCl	35.1
HYDROCARBON FRACTION	61.6
CARBON CHAR	3.3

DEGRADATION PRODUCT	G.C. %
CARBON DIOXIDE	6.5
C/5 HYDROCARBONS	4.5
C/6 "	1.6
C/7 "	1.3
BENZENE	11.8
C/8 HYDROCARBONS	24.7
2-ETHYLHEXANAL	1.4
PHTHALIC ANHYDRIDE	19.9

Figure 5: Analysis of the Hydrocarbon Portion of the Pyrolyzate

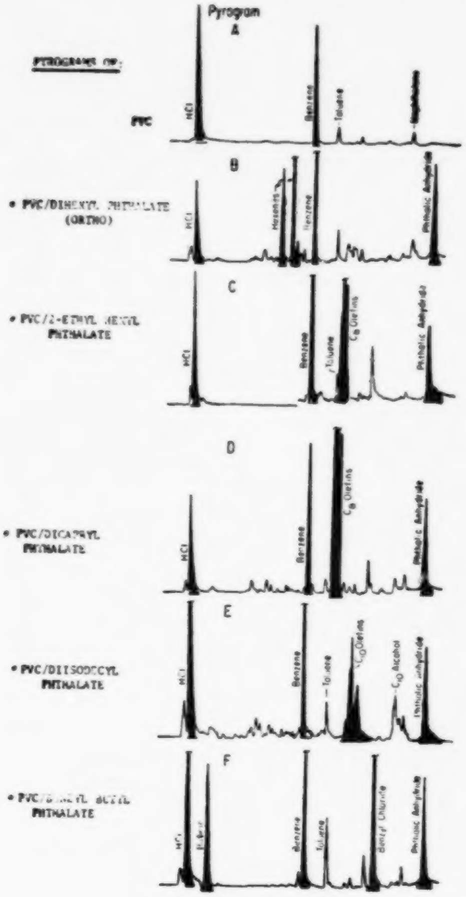


Figure 6: Pyrograms

ent ortho phthalate plasticizers were subjected to high temperature pyrolysis. The resulting pyrograms and compositions of these plastisols are shown in Figure 7. The first program is that of PVC homopolymer and is included as a point of reference. Typically, each program reflects the composition of each of the plastisols. The presence of phthalic anhydride indicates the general class of plasticizer (i.e., o-phthalate ester) while the olefin peak indicates the specific o-phthalate ester in the plastisol. It is evident that the technique can be applied to different classes of plasticizer such that the pyrogram indicates both the general class and specific nature of the plasticizer.

The question again arises as to the applicability of this information to actual combustion conditions. More specifically, if a PVC plastisol (i.e., o-phthalate ester plastisol) undergoes incomplete combustion, will the combustion gases contain phthalic anhydride and olefin derived from the plastisol? Although a direct analysis of the combustion gases from a PVC plastisol is available, that analysis did not include the plasticizer because of its non-vola-

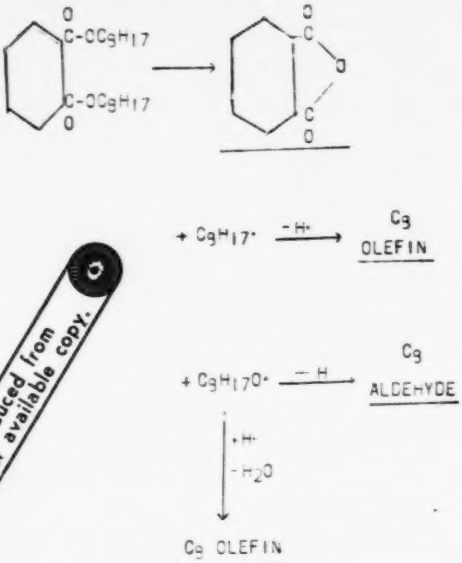


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Figure 7: Degradation of Plasticizer

tility.[15] It was assumed that as the plastisol was heated from 200°C to 600°C, plasticizer slowly boiled off the plastisol, and this was accompanied by partial combustion. Recent work indicates that this assumption may not be valid. Differential thermal analyses of a series of PVC plastisols has shown that in heating a plastisol under programmed temperature conditions, an exotherm due to the decomposition of the plasticizer occurs *before* the exotherm due to plasticizer evaporation.[16] The decomposition products of the phthalate ester were found to be phthalic anhydride and olefin hydrocarbon.

Pyrolysis of Chlorinated PVC

Post chlorination of polyvinyl chloride results in polymer that can contain up to ~73% chlorine (vs. ~56% for PVC). Recent studies involving the pyrolysis of this material suggested that chlorinated PVC might be precursor for chlorinated hydrocarbons.[17] If chlorinated PVC did give a high yield of chlorinated hydrocarbons under pyrolytic conditions, reclamation of waste chlorinated PVC could be considered as a basis for the production of chlorinated hydrocarbons. In order to investigate this possibility, we carried out a complete analysis of the pyrolysis products from this material. Although a series of chlorinated hydrocarbons are formed during pyrolysis as indicated by Tsuge[17], the yield of these materials is extremely low. The overall degradation profile indicates that over 90 percent of the polymer is converted to HCl and a carbonaceous, chlorine free ash (see Figure 8).

OVERALL DEGRADATION PROFILE

- HCl..................68.6
- HYDROCARBONS........ 5.7
- CHAR(Cl FREE).......25.7

HYDROCARBONS	%
• BENZENE	25.8
• TOLUENE	TRACE
• CHLOROBENZENE	37.0
• DICHLOROBENZENE	26.1
• DICHLOROBENZENE	11.1

Figure 8: Pyrolysis of Chlorinated Polyvinyl Chloride

Quantitative Analysis of HCl by Pyrolysis-Gas Chromatography

During the initial studies involving the pyrolysis of PVC, it became apparent that a quantitative analysis of the HCl formed during pyrolysis would be highly advantageous, especially with respect to PVC plastisol and chlorinated PVC pyrolyses.

The first chromatographic peak in the pyrogram of PVC is due to the elution of HCl and very small amounts of methane. In order to test the reproductibility of this peak with respect to the amount of PVC pyrolyzed, a series of PVC samples in the range of 10-20 mg were pyrolyzed at 600°C, and the area of the resulting chromatographic peak due to HCl was measured. The relationship of peak area to weight of polymer degraded is illustrated in Figure 9. Aside from the first run (pyrolyses were carried out in succession; that is, the chromatograph was kept at ambient temperature during each of the six runs. In the way, the pyrolysis products were

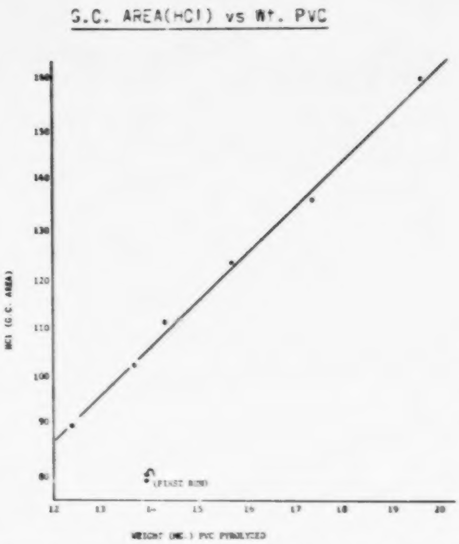

Figure 9: HCl (Gas Chromatogram Area) vs. Weight of Polyvinylchloride Pyrolyzed

trapped on the column and did not elute during the HCl analyses) the remaining analyses provided a linear relationship between the two variables. The inaccuracy of the first run or analysis was interpreted as being due to an initial conditioning process by the first slug of HCl through the metal columns. To test this, a stainless steel tee joint containing a septum was added to the pyrolysis unit. In this way, a small amount of gaseous HCl could be injected into the system prior to the first pyrolysis. When this preliminary conditioning step was carried out, it was found that the first run of the series correlated with the remaining runs.

When PVC homopolymer is used as a standard precursor of HCl (i.e., 58.3%), the amount of HCl released from other chlorinated hydrocarbons during high temperature pyrolysis can be calculated. This technique involved the pyrolysis of the standard and the unknown compound in a series of runs in which the weight of each of the samples and the corresponding HCl chromatographic peak areas are recorded. These various quantities can be related in an emperical formula which results in the calculated percent of HCl from the unknown.

A series of polymers ranging from chlorinated polyethylene to chlorinated polyvinyl chloride were analyzed for evolved HCl by this method. The results of this study (see Figure 10) indicated that the amount of HCl formed during high temperature pyrolysis could be determined within 0.6% of the theoretical value.

SAMPLE TYPE	HCl (found)	HCl (theo)
PVC PLASTISOL	30.1	29.1
"	37.0	37.3
"	44.7	44.5
PVC-COPOLYMER	53.5	52.9
"	46.3	46.3
PVC compound	38.5	38.6
"	47.5	47.7
Cl-POLYETHYLENE	34.9	34.3
"	40.7	41.1
Cl-POLYVINYL CHLORIDE	63.9	69.2
"	69.5	71.5

Figure 10: Typical Analyses

CONCLUSIONS

The applicability of pyrolysis-gas chromatography to problems in waste disposal is evident. It offers a method by which materials can be characterized with respect to their thermal degradation products. Since the mechanism of the flammability of polymers involves initial pyrolysis of the solid polymer followed by combustion of the pyrolysis products, pyrolysis-gas chromatography offers a method in which the pyrolysis products can be generated and measured quantitatively and qualitatively.

From these basic laboratory experiments, it is evident the pyrolysis of these materials can result in a total reclamation of HCl. The feasibility of this method to large scale waste disposal problems remains to be established.

REFERENCES

1. McKinney, R. W. *Journal of Gas Chromatography*, 2. 1964, p. 432.
2. Perry, S. G. *Journal of Gas Chromatography*. February, 1964, p. 54.
3. Barbour, W. M. *Journal of Gas Chromatography*. July, 1965, p. 229.
4. Levy, R. L. *Chromatography Review*, 8. 1966, p. 48.
5. Alishoyev, V. R. *Vysokol. Soyed. A-11:* No. 1. 1965, p. 247-51.
6. Giddings and Keller. *Advances in Chromatography*, Part 7. Marcel Dekker Inc. New York, 1968, p. 221.
7. Schmitz, E., and Wogrally, E. *Allgemeine Und Praktische Chemie*, 20. July, 1969, p. 251.
8. Darnay, A., and Franklin, W. E. Midwest Research Institute Report SW-5c). U.S. Department of Health, Education and Welfare, 1969.
9. Fulmer, M. E. and Testin, R. F. "Role of Plastics in Solid Waste," Battelle Memorial Institute, Columbus Laboratories. Prepared for the Society of the Plastics Industry, Inc.

10. Research Project by Kaiser and Carotte of New York University, Department of Chemical Engineer. Sponsored by the Society of the Plastics Industry, Inc.

11. Fenimore, C. P., and Martin, F. J. *Combustion and Flame*, *10*. 1966, p. 135.

12. Fenimore, C. P., and Jones, G. W. Ibid, p. 295.

13. Learmonth, G. S., et. al. *British Polymer Journal*, *Volume 1*. July, 1969, p. 149.

14. Watson, J. T., and Biemann. K. *Analytical Chemistry*, *36*. 1964, p. 1135-7.

15. Boettner, E., et.al. *Journal of Applied Polymer Science*, *13*. February, 1969, p. 377, 91.

16. Dunn, P., and Ennis, B. C. *Journal of Applied Polymer Science*, *14*. 1970. p. 355-64.

17. Tsuge, S., et.al. *Macromolecules*, *2*. #3, May/June, 1969, p. 277.

Grinders, Shredders, Crushers or Fragmentizers

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There is a need for improved materials handling, whether solid wastes are to be disposed by landfill, incineration plus landfilling incinerator residues, or whether an attempt shall be made to recover components or convert them into materials that might be recycled into the economy. One way, and perhaps the only way, to achieve this is to reduce the particle size range of the materials. The data presented was obtained as part of a study for the U.S. Public Health Service aimed at analyzing the state of the art with respect to potential recovery of solid waste components.[1] They are believed to be applicable to solid waste processing, whatever the intent the processor might have.

Emphasis was placed upon obtaining cost and performance data from literature, patent files, equipment manufacturers, and currently operating refuse reclamation and disposal plants. A previous study conducted by Battelle indicated that the published literature is not an adequate source of the cost and performance data desired.[2] Consequently heavy reliance was placed, as information sources, upon manufacturers and operators of equipment and processes that could be used in various aspects of solid waste recovery. During the study, over 200 such contacts were established.

Primary problems encountered during the study were the lack of existing operational data, questionable reliability of available data, and proprietary constraints which made it impossible to obtain some data. Whenever possible, engineering estimating procedures were employed to fill data gaps. Where the generated estimates are not sufficiently reliable or could not be developed, recommendations were provided for specific programs designed to generate missing data either through research or demonstration study programs.

Equipment Characteristics

Size reduction, in general, employs three basic forces — compression, tension, and shear in various combinations. In the course of the research program, nine basic types of size reduction equipment were investigated: (1) crushers (2) cage disintegrators: (3) shears; (4) shredders, cutters, and shippers; (5) rasp mills; (6) drum pulverizers; (7) disk mills; (8) wet pulpers; and (9) hammermills.

All except cage disintegrators, cutters, and disk mills have direct potential applications in municipal solid waste size reduction; hammer-

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mills are by far the most popular, being used in about 90 percent of the existing systems.

Theoretical Power Requirements

The power requirements for size reduction of material by tension are, in general, higher than for brittle material because of the large elongation required to produce separation. For comparison purposes, theoretical requirements were computed for reducing large sheets of 0.05-inch ductile steel to 6-inch and 3-inch squares.

The following assumptions were made:

1. A 1-ton grip force to produce a 1-inch deep corrugation
2. A yield strength of 50,000 psi
3. An elongation of 20 percent, and
4. A yield occurring for 3 inches on each side of the fracture line.

On the basis of these assumptions, calculations were made that yielded the following results:

1. Power required to reduce the steel sheet to 6-inch pieces - 6.4 HP-hr/ton
2. Power required to reduce the steel sheet to 3-inch pieces - 13.5 HP-hr/ton.

The tearing of wood, as an example of a more easily reduced component of solid waste, may be compared to the tearing of steel by applying density, strength, and yield factors and by assuming the same size pieces. Assuming densities of 0.28 lb/in^3 for steel and 0.023 lb/in^3 for wood, a strength ratio of 50,000 to 4,000 psi, and a yield ratio of 20 to 10, theoretical power requirements for the size reduction of thin wood sheets to 6-inch and 3-inch squares is computed as follows: Power required for 6-inch pieces (wood) = 6.4 × 28/2.3 × 4,000/50,000 × 10/20 = 3.1 HP-hr/ton, power required for 3-inch pieces (wood) = 13.5 × 3.1/6.4 = 6.4 HP-hr/ton.

As expected, the actual power requirements of current equipment were found to be considerably higher than the theoretical values.

Performance Data

Performance data were collected on a total of 27 size reduction machines manufactured by 21 different companies. The data presented in Figure 1 are from manufacturers' ratings, the theoretical calculations outlined above, and to a limited extent, from existing installations. The various circles, boxes, etc., in Figure 1 represent data from different equipment designs, keyed as follows:

○ HAMMERMILLS

□ DRUM PULVERIZERS

△ RASP MILLS

⬡ SHREDDERS

The upper shaded area on Figure 1 includes size reduction equipment applied to automobile body size reduction. The lower shaded area includes equipment processing other bulky material such as harbor waste. Below both cross-hatched area fall machines operating on selected solid waste or on wood products. At the bottom of the chart are lines representing the theoretical power requirements for the reduction of wood and steel sheets to 6-inch pieces.

Based on the results shown in Figure 1, certain qualitative assessments can be made regarding efficiencies by comparing operating data from machines operating on particular types of wastes (metal, refuse, etc.) with the theoretical requirements for steel or wood. In general, it can be seen that on a percentage efficiency basis, the reduction of wood products is highly efficient when compared to the reduction of steel.

Direct comparisons of individual equipment items are impractical due to the wide range of materials, machine size, and product size represented. A general trend toward higher unit power requirements (hp-hr per ton) for the larger machines — even from the same manufacturer — was noted, and qualitative calculations were made that indicate that the smaller machines may be more efficient. Based on this and other observations, it appears that combinations - such as preliminary shearing operations, crushing feeders, or shredding members particularly in hammermills would show synergistic effects on municipal solid waste.

Of the 27 machines with applicable power data, data for 6 were based on unsorted municipal solid refuse, data for 10 based on processing sorted waste, and data for the remainder were based on either wood only or metal car bodies. The following input-material factors were derived by averaging the hp-hr per ton values for each of the above materials and relating them to 1.00 for municipal solid waste:

Mixed municipal solid waste	1.00
Sorted municipal solid waste	0.65
Wood (or fibers) only	0.43
Automobile bodies	2.82

Product characteristics are also a very important factor in size reduction. For a homegeneous material, the classical relationship of power-to-surface area is often applied. However, on a heterogeneous material such as municipal solid

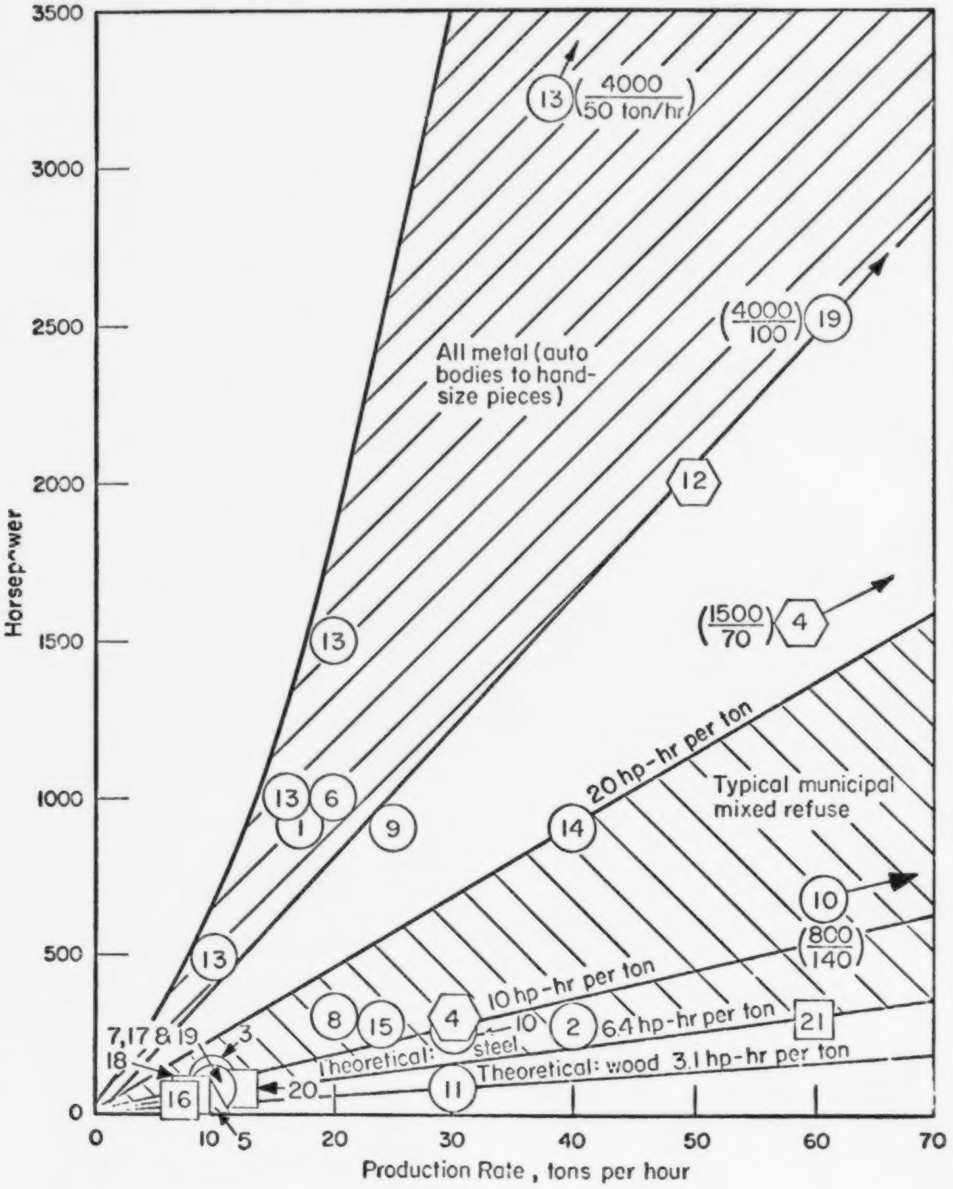

Figure 1: Size Reduction Power Requirements

waste, experimental data were examined which indicate that the following relative product size factors apply:

Six inch square pieces	1.00
Four-inch square pieces	1.39
Two-inch square pieces	1.64
One-inch square pieces	2.38

Applying the input material and product size factors to the available data, the performance data from Figure 1 are plotted in adjusted form in Figure 2. It is seen that the data scattering on this graph is much less than that of Figure 1, indicating that the rough correlation factors provide a means of making the data more useful.

Cost Data

Twelve of the companies contacted during the research program provided cost data applicable to size reduction of municipal waste. Two Demonstration Grant Projects sponsored in part by the Bureau of Solid Waste Management provided complementary data on two types of size reduction equipment — the rasp mill at Johnson City, Tennessee, and a hammermill at Madison, Wisconsin.

Standard cost estimating techniques and the adjustments discussed above for input material and product size variations were used on these data. (It was assumed that production is on the basis of single 8-hour shifts for a 5-1/2 day week, 52 weeks per year).

Approximate capital costs of the basic size reduction equipment units with capacities adjusted to the theoretical value for municipal solid waste input and a 6-inch product have been plotted (Figure 3). Although the data are somewhat scattered, as was the case with raw operating data, the scatter in the original raw cost data has been reduced. The trend shown indicates that the capital cost of size reduction equipment applied to the unsorted refuse does not increase linearly with capacity,

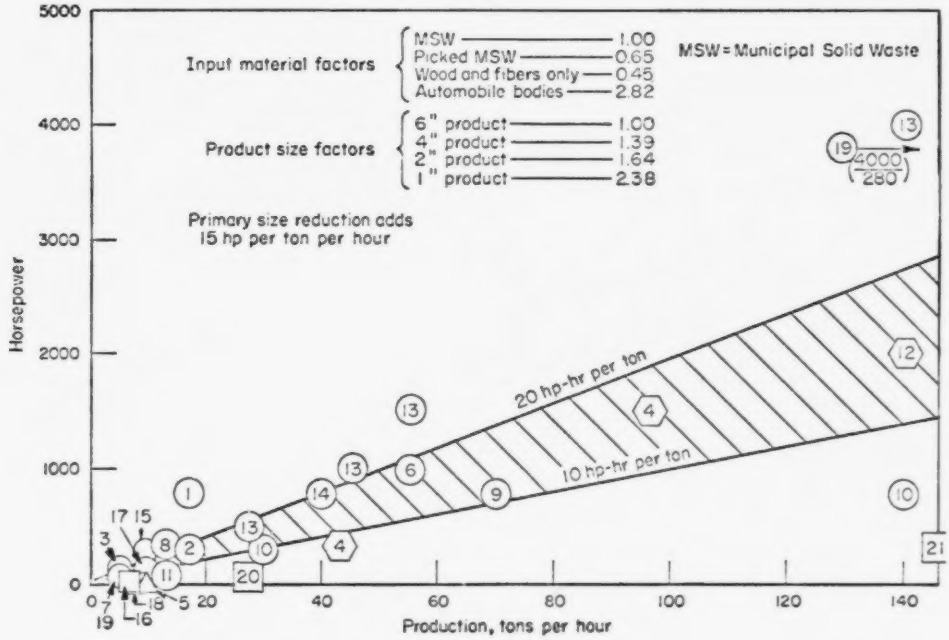

Figure 2: Adjusted Power Requirements

but follows the classical 0.6 exponent relationship.

In addition to the production rates mentioned above, the following were included in the calculations to obtain operating data:

1. Maintenance: manufacturer's data modified by user's information and estimates from averages of similar equipment
2. Equivalent annual cost (6 percent, 10 years)
3. Power: 1 cent/hp-hr
4. Labor: $10,000/year.

These maintenance and operating costs, again adjusted to mixed municipal refuse and a 6-inch product size are plotted in Figure 4.

It must be emphasized that the municipal solid waste size reduction cost figures presented here are very qualitative because of the wide variation in machines, material and product size. They do represent, however, the best generalized data available at this time.

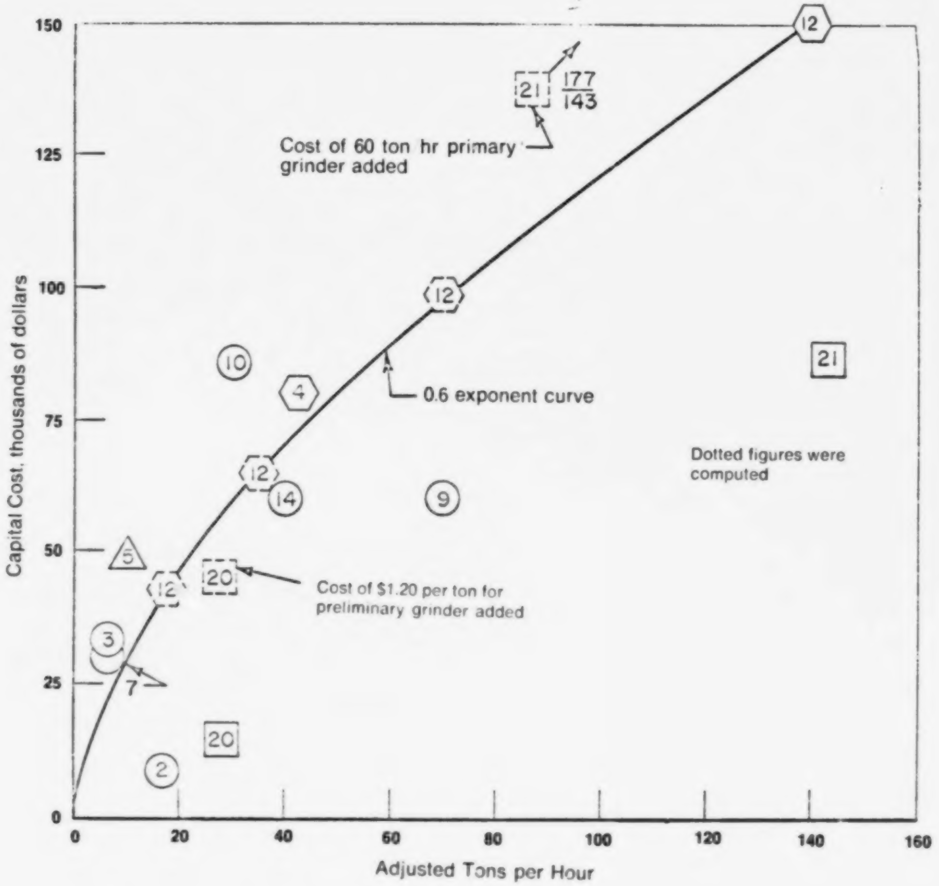

Figure 3: Capital Cost of Size Reduction Equipment

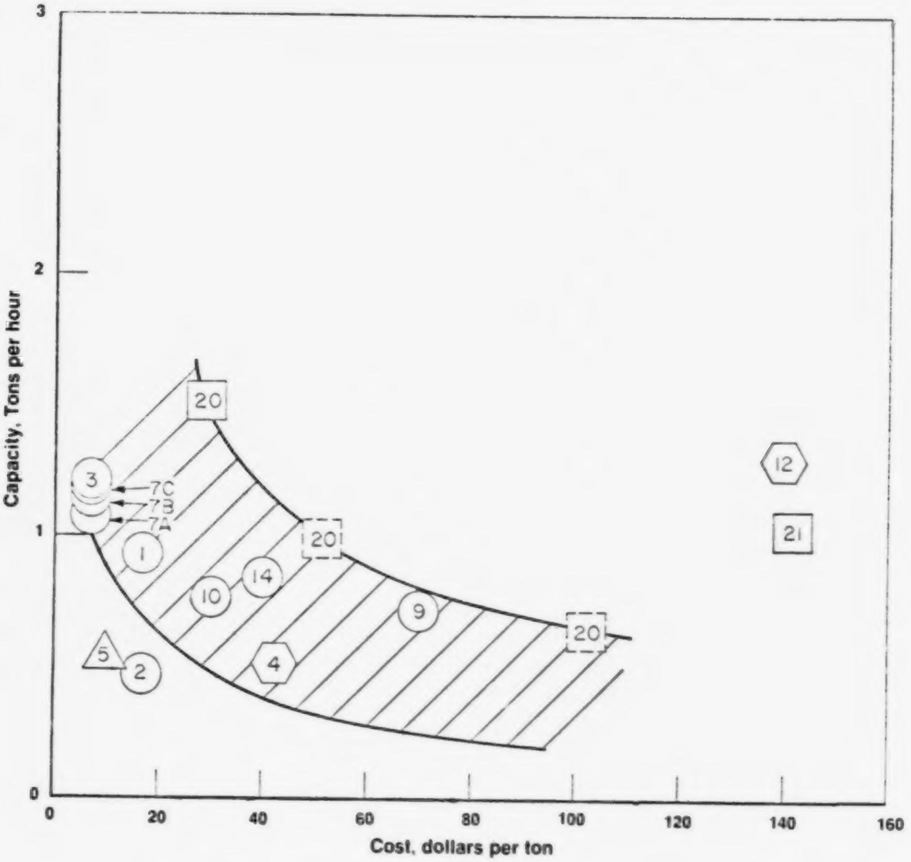

Figure 4: Maintenance and Operation Costs of Size Reduction

REFERENCES

1. Drobny, H. L., Hull, H. E., and Testin, R. F., Recovery and Utilization of Municipal Solid Waste - A Summary of Available Cost and Performance Characteristics. Public Health Service Publication No. 1908, Washington D. C., U.S. Government Printing Office, 1969.

2. Engdahl, R. B., Solid Waste Processing: A State-of-the-Art Report on Unit Operations and Processes. Publication No. 1856, Washington, U.S. Government Printing Office, 1968.

Balers and Compactors

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Industrial Services of America

More trash, fewer nearby disposal sites, stricter pollution laws, increased labor costs, and high cost of salvage are the current realities making industry's trash handling and disposal one of the most urgent problems facing plant managers today.

The greatest increase in the volume of trash generated today is a direct outgrowth of our ever-increasing productivity. Industry generates about 85 billion pounds of trash per year. This represents only 25 percent of the total volume of trash generated by the nation as a whole — about 340 billion pounds annually. That national figure is expected to increase to 450 billion pounds by the end of 1976, and with it industry's contribution. It takes little imagination to realize that the nation faces a staggering problem of disposing of its trash, maintaining a clean and healthy environment, and keeping costs down. For example, automotive assembly plants estimate that they generate 50 pounds of corrugated trash for every car assembled. In 1968 they assembled 9,000,000 cars, thus producing 450,000,000 pounds of trash.

This is only corrugated! Add the wood from pallets and crates, the rail-car dunnage, steel strapping, and trash barrel rubbish, and the figures from this industry become staggering.

The yearly rate of increase of packaging materials which must be disposed of can be estimated by the production figures for corrugated board. In 1957, 7.3 million tons of corrugated were produced in the United States. In 1967 that figure was 12.2 million tons, reflecting a 4 to 6 percent annual average rate of increase. The experts predict continued increases not only in the total volume but also in the rate of growth itself.

The handling and disposal costs for this trash are on the rise. Plants in urban and suburban areas have had to shut down incinerators which are too small, too expensive to operate, and too air-polluting. Responsible businessmen, aware of the need for good community relations, have phased out their incinerators and turned to dumping. But as these communities have grown, suitable nearby land for dump sites has become scarcer which means that trash must be hauled greater distances.

It is the genius of American industry that it finds solutions to the very problems it creates. However, plants do not automatically adopt new ideas or new techniques even though they may be available. Nevertheless, there is a growing awareness that the solid waste disposal problem is worthy of study in depth.

The aim of industry, however, should be to achieve the most efficient means of handling and disposing of trash at the lowest possible cost. In most cases this can best be done in collaboration with a reputable private hauler who will be responsible for removing the trash from the plant and disposing of it. But the in-plant collection system must be efficient in itself if the cost of trash handling is to be kept at a minimum.

One should not be confused by the problem of salvage. Salvage is merely another means of disposal, a means whereby the plant hopes to get revenue for its waste cardboard or paper. But in any salvage operation, the cost of salvaging waste must not exceed the revenue received from the waste-paper dealer if you want to come out ahead. One rule must also be kept in mind: the less trash is handled, the less it costs to dispose of it. One way to eliminate excessive handling and sorting is to have the salvageable material segregated at the point where it is generated by the men who generate it. This means setting up a collection system with different containers for different kinds of trash. Thus the costly sorting process is taken care of at the outset.

There is some argument whether or not it pays to have a salvage operation. But if the corrugated paper is not salvaged it will have to be disposed of anyway. Salvage can be profitable, and the demand for salvaged cardboard will always be there. For example, in 1967 25 percent of all produced containerboard was recycled, and paper mills expect that percentage of recycled material to increase in the coming years.

How much money is made depends largely on the volume, quality, reliability of supply and the cleanliness of the waste paper and corrugated to be disposed of. The dealer will pay the highest price if the volume is great and the supply reliable, the quality high, the condition clean, and if the material is baled. If all the dealer has to do is remove the bale of top quality salvaged material from the plant and deliver it to the mill that will yield the greatest return. But if the dealer has to grade the waste, pick out the coffee cups and plastic bags, and then bale it, the dealer will probably have to be paid to haul it away if he is to make a profit.

Thus, if one intends to do any salvaging, he must develop as efficient and inexpensive a means of segregating the trash at its origin. Once it is segregated, the disposable trash must be taken to the compaction unit and the salvageable material to the baler. Then the containers of trash and the bales of salvaged material must be removed from the premises. Here is where the outside contractor normally takes over. The paper dealer will remove the bales, and the contractor will haul away the containers to the landfill. Who owns what equipment will be a matter for agreement between the plant and the contractor. Today, there are no set rules. Any arrangement that benefits both parties and does the job is desirable. A great deal of flexibility regarding the leasing or renting of equipment is possible.[1]

The economics of today's industrial trash handling and disposal operations make it virtually inevitable that one will want to use an integrated equipment system — of which there are many available to fit the needs of any particular trash handling situation. The chief benefits of the integrated equipment system are that it permits a plant to dispose of more trash per highway truck pick-up, and it permits one single highway truck operator to handle a multiplicity of detachable containers. Today the trend is to reduce the number of trips to the landfill and increase the payload per trip in order to attain the lowest possible cost per ton mile. The stationary or fixed compactor is the best way to achieve this with large volumes of unincinerated trash. This equipment unit, however, is still largely a mystery to over 70 percent of the plants in this country.

The concept of stationary compaction is not a breakthrough for the solid waste industry, but rather an extension of a trend. Most readers of this article are familiar with the distinctions in freight rates applied by trucking companies and railroads to volume versus weight and are well aware of the fact that high density material is cheaper to ship than low density material. Most everyone is aware of the fact that the difference in operating cost for a fully loaded vehicle is minimal compared to a partially loaded one. Basically, therefore, the idea of stationary compaction is merely to take advantage of this very minimal differential and greatly increase the revenue per man truck hour. In doing so, it will be found that in many instances you will have lower costs, as the greatest percentage of solid waste collection costs stem from the frequency with which you have to remove material from a location.[2]

There are now available several stationary or fixed compaction systems from several manufacturers. All of the systems have a similar range of components: collection carts, compactors with life mechanisms to dump the cart's load into the compactor with its hydraulic ram, containers into which the trash is compacted, and highway trucks capable of hoisting and hauling away the filled container to the dump, returning it empty to the plant, and replacing it in position with the compactor. All of the components can be found in different sizes and configurations. For example, some compactors have sideloading hoppers, while others can be loaded from an overhead ramp. There is a wide variety of collection carts, container sizes and truck units with different capacities.

The compactor, usually installed at the truck dock, consists of a charge box with a hopper opening into which the trash is thrown and a hydraulically operated ram head which pushes the trash through an opening into the attached accumulation container.

The object is to achieve as high a compaction ratio as possible. To do this, the ram merely pushes the trash a little ways forward into the container. As the box fills up, the constant ramming of trash against trash compacts it.

When the container is full, it is detached and taken away by the hauler. The hauling equipment is especially designed to hoist the container onto the truck easily in about two minutes.

The most obvious benefit of the stationary compaction system is that it sharply reduces the number of trips the hauler must make to the dump — thereby reducing hauling costs to their minimum. This is especially important if the dump site is distantly located.

The second clear benefit of compaction is that it permits the accumulation of a tremendous amount of in-plant trash in a comparatively small amount of space, thus freeing valuable warehouse, trash room, or dock space for other uses. In addition, the container permits an accumulation of trash over several days without the penalties of unpleasant odor, rodent infestation, and bad housekeeping which are the usual consequences of open trash accumulation over a period of days.

Pilferage is another cost which has been cut in many instances by the use of a compactor. Much backdoor pilferage in large retail establishments and assembly plants takes place through the trash disposal system, with employees hiding cartons of pilfered goods in containers of loose trash, which they then recover after the trash is hauled away from the plant or store. With a compaction system, this method of pilferage becomes impossible because compaction damages the pilfered goods.

The better housekeeping provided by the compactor and container provide a number of benefits with savings which are difficult to estimate but which, in the long run, often add up to a substantial sum. For example, better housekeeping eliminates the need for men to spend time rearranging trash and tidying up. It reduces the possibility of accidents involving loose trash, resulting in damaged equipment and loss in time. It eliminates the clogging of aisles with trash, thereby slowing down fork truck movements. It makes it possible to remove trash from production areas more quickly, thus reducing the likelihood of production interruptions or slowdowns due to trash accumulations. Here, smaller compaction units located at points of trash generation in assembly plants can greatly cut down the costs of in-plant trash collection.

A compactor and container also eliminate dangerous fire hazards created by loose burnable trash. Elimination of this hazard could result in lower fire insurance rates for the plant. In addition, plant safety is enhanced by eliminating the hazards of nails, broken glass, splinters, and sharp edges often found in loose industrial trash. Employee injury is thus reduced and with it injury compensation costs.

Last but not least is the aesthetic benefit resulting from an improved, cleaner environment. With the public — and management — becoming more and more conscious of environmental pollution, nothing is more unsightly and damaging to a company's image than masses of loose trash around the back door of a plant or store. What was tolerated a few years ago, because everyone was doing it, is no longer tolerated. The public expects a company to show aesthetic concern by not cluttering up an area with unsightly trash.

Generally one manufacturer will be able to supply all of the components of a particular system but some components, particularly containers, have been manufactured to be compatible with other manufacturers' systems. It is always important to check equipment compatibility in the event that there is a need to mate the equipment of various manufacturers.

In choosing the right equipment one should know how easy it is to service and maintain, how systematic it is, and what its utilization will be. It might be worthwhile in some cases to buy the equipment, lease it, rent it, or simply use the hauler's equipment with some sort of agreement. In some cases it may be worthwhile to buy used equipment.

There are presently about three sizes of compaction systems on the market. The smallest is of most recent development, created to meet the needs of high-rise dwellings and commercial buildings which are phasing out incinerators in order to avoid air pollution. Equipment manufacturers are not meeting this demand with a wide selection of small compaction units, varying in charge box capacities (1/2, 1, 1.2, 1.25, 1.8 cu. yds.), engine horsepower (from 1 HP to 10 HP), and compaction force (from 7,000 lbs. to 55,000 lbs.), designed specifically for multi-story building use. Units in this category are also being developed for in-plant use at the point of trash generation where the trash is compacted into a collection container.

The second category of compactors — for commercial and light industrial uses, with charge box capacities from 2 to 3 cubic yards — will be found at shopping centers, retail stores, supermarkets, distribution centers and warehouses, restaurants, amusement parks, hospitals, motels, food processing plants — where the trash is not bulky, fits easily into the charge box opening, and goes into the kinds of pick-up containers serviced by local haulers. A high-volume company cafeteria in a sprawling plant would fit this category. The choice of compactor in this range will be determined basically by volume requirements and by how the trash is deposited in the unit. Volume and size of trash will determine size of compactor, while configuration will be determined by how you want to feed the unit.

The overall dimensions of the unit will also be important if space requirements are a problem. For example, one may find available two compaction units with identical capacity and power but different overall dimensions. Everything else being equal, choose the compactor that best fits into the space provided.

In this second category, charge box capacities are available at 2, 2.2, 2.5, 2.9, and 3 cubic yards. Motor horsepower varies from 7½ HP to 20 HP. Compaction cycle time varies from 26 seconds to 54 seconds. Compaction forces in this category also vary greatly — from as low as 28,000 pounds to one unit offering 112,000 pounds.

The third category of compactors — the heavy-duty industrial compactor — is in the charge-box capacity range between 3.5 cubic yards and under 7 cubic yards. This is the compactor most suited to the widest range of industrial trash handling requirements. Compactors in this category are built to handle wood pallets, triple-wall corrugated boxes, skids, cement blocks, metal drums and other such items, as well as general trash. In this category, compaction forces run from 90,000 pounds to 112,000 pounds. Charge boxes are available in 3.5, 4, 4.2, 4.4, 4.5, 4.7, 5, 5.2, 5.9, 6 cubic yard capacities. Motors vary in horsepower from about 29 HP to 45 HP. Hydraulic systems vary greatly in cylinder diameter and stroke (from 6 inches to 8-1/16 inches in diameter and 68 inches to 116 inches in length of stroke), pump capacities (from 29.5 gpm to 84 gpm), and tank capacities (from 20 gallons to 240 gallons). Compaction cycles are as short as 29 seconds and as long as 45 seconds. To provide extra strength, some ram plates are pushed by two hydraulic cylinders in tandem instead of just one.

In selecting an industrial compactor with its usually large truck size container, the plant must know what kind of hauling services are available locally. If there is no hauler in the area with the equipment to handle a large trash container, one may have to buy or lease his own hauling equipment or help a local hauler get new container handling equipment. Generally, an equipment manufacturer will help set up a hauling system to accommodate large containers.

The results of compaction are obvious. If compaction of the material at the plant site is achieved by anywhere from 3 to 1 to 7 to 1, fewer trips to the disposal site will be required. Disposal costs, however, will be increased because heavier loads will be taken away. Whether the load goes to an incinerator, landfill site, transfer station or some other means of disposal, there will be additional costs involved in the compacted load, even though the rate is based strictly upon volume since disposal operators cannot afford to receive a high density load for the same costs as one of low density. The overall cost to a plant for compaction service is reduced even though the proportion of the overall costs relating to equipment is increased.

Refuse handling systems start with the push carts placed at points of refuse accumulation. They eliminate double handling of refuse. Carts can be adapted for connecting together and pulled in train like lines. They vary in size from 1.5 to 4.0 cubic yard capacities and can be dumped mechanically or hydraulically. The heart of a refuse removal system is the stationary compactor. The unit may be installed at a dock, in an open yard, or through a wall. The compactor forces and compacts refuse into an attached container. A variety of containers are available for use with the compactor. Refuse is reduced to a fraction of its original volume by tons of hydraulic ram pressure. A complete line of commercial and industrial compactors are available, as discussed earlier, that can handle refuse in volumes ranging from 810 cubic feet to 352 cubic yards per hour.

Containers are engineered and constructed for long life and to withstand the repeated compaction pressures. Closed containers are available in capacities from 33 to 42 cubic yards.

Truck and trailer lift-hoists can handle a wide variety of detachable containers. Containers are pulled on the hoists frame by a hydraulically operated winch.

A typical heavy duty compactor used by industry for large volumes of waste generated is the TP-77 compactor manufactured by the TRI-PAK Division of Industrial Services of America, Inc.

The TP-77 compactor is the heart of the TRI-PAK refuse removal system. It is designed for use as a transfer station or heavy industrial use.

The TP-77 compactor features automatic pushbutton controls, rugged construction, standardized hydraulic and electrical components, and continuous feed operation. Optional manual controls may be substituted for the automatic controls if desired. The hydraulic power pack and controls are designed to facilitate easy maintenance, inspection, and repair of hydraulic and electrical components.

There is no need to segregate the refuse fed into the compactor. Materials to be disposed are pushed into a TRI-PAK container and reduced to a fraction of their original volume by compaction force of 100,000 pounds. This force is developed by 1750 psi hydraulic pressure being applied to one 8½-inch hydraulic cylinder. To help seal off compacted loads, it is possible to switch to manual cycling which allows the pressure to be increased to 2000 psi and the compaction force to be increased to 112,000 pounds. During normal cycling an indicator light shows when the container is full.

The machine weighs 17,500 pounds and has a charging box capacity of 7½ cubic yards. The compactor is rated at 557 cubic yards per hour at 80 percent utilization. The cycle time is approximately 40 seconds. The container is held to the compactor by two adjustable clamps capable of sustaining the compactor's total thrust.

The machine has automatic, pushbutton, and timer controls. The forty horsepower motor operates on 22/440 volts, 3 phase, 60 cycles.

The compaction cylinder is 8½-inch diameter double acting with 144-inch stroke. The hydraulic pump capacity is 106 gpm and the hydraulic reservoir capacity is 300 gallons.

Truck lift hoists, manufactured and installed on customer trucks by TRI-PAK, not only handle TRI-PAK's standard closed and open container, but can also be used to handle a variety of roll-off containers. With a frame length of 22 feet, the truck lift hoist permits loading of a 22-foot long container. Operation of the lift hoist can be handled by one man, saving operator costs. After hook-up, loading is controlled from one point. Equipped with an open container, the truck mounted hoist can be used as a dump truck.

Container loading is safe and simple:

(1) The hoist frame is fully tilted by its two hydraulic cylinders.

(2) Lift-hoist cable is connected to the container.

(3) Container is pulled slowly onto the frame by hydraulically operated winch.

(4) Frame is lowered as container rolls on.

(5) When container is fully loaded, a set of locks is engaged securing the container to the frame.

At destination, the container can be unloaded by reversing the loading procedure or contents can be dumped by raising the hoist frame using the hydraulic cylinders.

It should be noted that in choosing equipment, the buyer will find a wide variety of standards used in describing sizes and capacities. The buyer should have a clear idea what the manufacturer means by a particular size designation. No two manufacturers agree on the meaning of size designations. One might use the following check list of questions to find out if the unit being offered is of the quality and capacity required.[3]

(1) Will the hopper or charge box easily accommodate the largest item of trash generated by the plant?

(2) Is the compaction force sufficient to handle wooden pallets and triple-wall corrugated if one must occasionally dispose of these items?

(3) Is the charge box big enough to accommodate the trash from one full pick up cart or container?

(4) Is the motor of sufficient horsepower to do the kind of job expected of the compactor?

(5) Is the ram head built strongly enough to provide prolonged service?

(6) Is the ram head backed up by a hydraulic cylinder and system of sufficient strength?

(7) Is the cylinder stroke long enough to get the trash well into the container?

(8) Is the compaction cycle fast enough to accommodate the rate of trash flow into the hopper?

(9) Is the compaction force sufficient to achieve the desired compaction ratio?

(10) Is the steel plating of the compactor and

container thick enough to prevent bulging and denting after extensive use?

(11) Is the coupling between compactor and container devised to make accidental detachment impossible?

(12) Are the motor and hydraulic systems easily accessible for maintenance and repairs?

(13) Will the compactor fit the available space?

(14) Will the dock space accommodate the largest size container economical and practical to use?

(15) Will the space be easily accessible to the container pick-up vehicle?

(16) Is there sufficient space so that the pick-up vehicle can maneuver around, pull away the full container, put an empty one in its place, and then haul the full container away?

(17) Is there sufficient room at the dock to accommodate trash carts or a conveyor leading to the hopper?

To check the economy of installing a compaction system, the following information should be obtained from the plant.

(1) Location of each trash generating point.

(2) Type of trash generated at each point.

(3) The volume of trash now generated at each point and how much larger this volume is expected to be about five years from now.

(4) The hazards to safety and health of the present trash handling system.

(5) Opportunities for pilferage through the present trash handling and disposal system.

(6) Amount of plant space presently required for trash storage and handling.

(7) Man hours presently spent on trash handling.

(8) Quantity and type of equipment now used for handling trash.

(9) Present methods and cost of hauling refuse to ultimate disposal site.

(10) Cost of indirect labor overhead involved.

(11) General state of plant cleanliness.

Once this information is gathered, one is ready to select the stationary compactor which would most economically and efficiently fit the situation. It is important to know the capacity of the compactor in terms of its ability to handle a plant's flow of trash over a period of time. To calculate the capacity of the compactor, the cycle time and displacement per stroke should be known.

If the compactor cycle time is 45 seconds and the compactor displacement is 2.5 cubic yards per stroke, calculate the compactor output by multiplying the compactor displacement by the number of seconds in an hour (3600) and divide that figure by the compactor output — 200 cubic yards per hour. To arrive at a more realistic, less than optimum 8-hour-day figure, use 80 percent of the hourly figure and multiply it by 8. This would tell about how much trash the compactor could handle in a normal 8-hour day.

Compactors are also beginning to play a major role in municipal waste collection and disposal because of their increasing use in transfer stations. In large metropolitan areas where there are many collection routes and long distances to the landfill disposal site, a transfer station becomes an economical operation. The refuse is dumped from the small collection trucks into a hopper, chute, or onto a conveyor belt which feeds a compactor which moves the refuse into or compacts it into large 40 or 50 yard containers or into 65 and 75 yard trailer trucks. The refuse from several trucks with a crew of from two to six is then hauled to the landfill by one truck and driver.

The pulverization process is also used at transfer stations instead of compactors. The advantage of the pulverizer is that it breaks the refuse into smaller pieces and actually gives the waste a different characteristic.

The controlling factor, however, is the legal load limit which can be hauled over the road in trucks. Haul by rail sets up new criteria which may mean the refuse would be pulverized and compacted.

For industrial purposes, the stationary compactor has played a major role in the last few years at bringing the solid waste handling problem under control, and it will have an even greater part to play in the future.

Balers

Balers, like stationary compactors, are made of many sizes for many different jobs by many different manufacturers. Balers are used primarily to bale paper, corrugated, and rags. They are used to bale scrap metal and non-ferrous material, whole automobiles, and they are now being designed to bale municipal refuse.

The paper baling process usually consists of throwing or pushing the waste paper or corrugated onto a feeder conveyor. The material then passes into a hogger or shredder which tears the scrap into small pieces and throws it in a high velocity air stream created by the exhauster of the hogger and then blows it into the separator located directly over the baler feed chute. The cyclone separators allow the air to escape and the scrap to drop into the baler feed chute. The separators are usually located on the roof directly over the baler.

As the scrap drops into the feed chute, the electrical controls take over. When the scrap builds up to the height of the electric eye in the chute, the hydraulic ram moves horizontally, compressing the scrap into one or more inches of bale length. When the bale has been formed to the desired length, the operator inserts the tie wires and ties the bale off as it moves forward and the next bale is being formed in the compression chamber. The baler is never stopped for bale removal. Bales are always uniform in size and rectangular in shape, made to any length, usually 72 inches. Density of bales is controlled automatically by frictional resistance in the baling chamber.

Horizontal balers, like the one described above, come in many sizes. One popular size bales 12 tons per hour. A baler of this size, however, is used in an operation by a paper dealer who runs a salvage operation.

Balers used in industry are limited to few operations because getting rid of corrugated is only a part of the waste problem and getting the waste out of the plant is the biggest concern, which is why stationary compactors play such a major role in waste handling today.

There are also small paper balers on the market today, and they usually do not require hogging. Several large retail grocery chains today have small vertical balers in each store. Cardboard boxes are thrown in a chute, and a single ram travels down until full pressure is reached. The weight of these bales are usually around 300 pounds compared to 1200 to 1400 pounds for the larger bales.

The hydraulic presses used in the scrap iron business are completely different from the paper baling industry. Triple compression heavy-duty hydraulic presses turn out high density bales that weigh from 4000 to 7000 pounds each. The bales usually measure 36" × 24" × 60" average length. A bale of this size will weigh 375 tons and is ideal for a large size scrap yard.

Scrap is loaded into the hopper and automatically weighed and recorded before it is dumped into the 920 cubic foot charging box. The first compression ram moves in from the end of the box with a 494 ton force, followed by a second ram from above and the third ram from the side, each with 1500 tons of force. The third ram also pushes the finished bale through the vertical gate and onto a chute.

The bulk of municipal refuse, the long haul to the disposal site, and the advantages of a transfer station operation have led to much research into using high density scrap balers to bale municipal refuse. There have been many problems to develop, as expected on any research and development project, and to date there are no cities in the United States which are baling refuse, putting it on a rail car and moving it 200 miles to a sanitary landfill.

The Tezuka Refuse Compression System from Japan has received much publicity in this country. The American Public Works Association Research Foundation has visited Japan and made a study of this operation. The APWA published a report on this study and their basic conclusions were:

(1) The specific cost/performance values of the Tezuka process and its individual system elements can not be determined from the data presently available.

(2) Overall, the Tezuka system appears to be complicated and, in part, very cumbersome.

(3) It is probable that the Tezuka process can be appreciably improved through additional process engineering.[4]

REFERENCES

1. Modern Materials Handling. "Trash Handling and Disposal". Special Report.

2. Rabins, Marshall. "Meeting the Challenge of Stationary Compaction". Solid Wastes Management. August, 1968, p. 6.

3. Modern Materials Handling. "Trash Compaction". July, 1969.

4. American Public Works Association. "The Tezuka Refuse Compression System." Research Foundation Demonstration Project DO1-00073.

Mechanized Reclamation from Municipal Solid Waste

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SUMMARY

The economics of reclamation of valuable components from mixed municipal refuse are briefly reviewed. Existing methods of sorting refuse into its useful and other components are described, and some of the current approaches toward mechanizing this process are outlined. The experiments presently being conducted at MIT are discussed in greater detail. It is concluded that the prospects for successful and economic reclamation of some of the major components of domestic refuse are bright.

INTRODUCTION

In the old days Grandma saved the string and wrapping from Christmas parcels, and old newspaper was bundled up for public works departments or churches to collect and to sell to paper merchants. The reasons why these wholly beneficial actions do not generally take place at present seem obvious but are worth restating.

The principal reason is that man has achieved such advances in mechanization of production that the number of man hours needed to supply him with his consumer goods is now a very small percentage of what it was in the past. It may, and probably does, require more man seconds of labor for a householder to bundle up the week's newspapers, and for these newspapers to be taken through the many stages of handling, baling, transporting, more handling, and repulping, than it does for trees to be cut, debarked, transported, chipped and pulped to make fresh newsprint. Because of the distorted economics and the political complications connected with the recovery of old newspapers, man has devoted all his inventiveness and energies on mechanizing the process for production of newsprint from trees, and almost no mechanization has been introduced into collection and handling of so-called 'secondary fibers'.

The second reason for this state of affairs is that there seems to be inexhaustible resources on the one hand, and large tracts where waste materials could be dumped on the other. Quite suddenly the cries of the conservationists that man was deluding himself have been heard. By a policy of consume and discard, man is destroying irreplaceable natural resources at both ends of the overall process: denuding a hillside or filling a bog are both death sentences to the fragile ecologies of these regions. Further, regardless of feelings or lack of them, for the sanctity of the various forms of life in these areas, the breaking of biological chains will and has seriously affected human existence in many ways, only a few of which are yet understood.

Accordingly, the need to take more steps to recycle resources is apparent. With some of the materials, for instance most plastics, there is no known method of re-use, and research must be undertaken to develop methods of re-using existing materials, or of formulating new materials which can be recycled, or of modifying the materials so that uses can be found. But for many of the significant components of domestic trash, there are well-established processes and industries based on them which can and do reclaim large quantities for materials — paper, glass, metals and textiles — and which could take much greater quantities if they were available. The main area where progress is required is in the movement of the material from the home and business to the processor. This area is broadly the concern of this paper.

The realm of this paper is even more restricted. It is taken as obvious that neither householders nor businesses will be willing or perhaps even able to revive their old habits of separating one trash component from another. If they were, the task of collection would become enormously more complicated. However, separating mixed trash after it has been collected to a central treatment plant requires less changes in existing patterns. In taking this approach man must accept the penalty that the value of some components (principally paper) will have been reduced by permitting the mixing.

This type of operation has in fact been in effect for many years. Some separation of valuable components from mixed trash has officially or unofficially taken place at incinerators and dumps. A degree of mechanization has been introduced in that frequently the feed to an incinerator will be by conveyor belt, and 'picking stations' with hoppers going down to baling presses have been arranged along the belt so that one man may have responsibility for removing clean newspapers, another corrugated cardboard, and so on. At one point an 'overband' magnet removes ferrous components. The largest operation of this type is that of the Lone Star Organics plant of Metropolitan Waste Conversion Corporation in Houston, Texas. Recently a paper removal machine has been installed, but the details are proprietary.

In this paper the possibilities of mechanizing central processing plants are discussed, and what is known of various existing methods are recorded. A progress report on investigations at MIT is given. Before describing the technologies, however, an attempt is made to show that the economics of separation can justify the investment involved in certain circumstances.

The Economics of Separation and Reclamation

Two approaches might be considered for the economic evaluation of methods of reclamation from refuse. One is to determine both the cost of separating each component, and the price which may be expected to be received for this component in various quantities. The wide fluctuations in the price obtained from year to year for waste materials make this line of attack uncertain. The second approach is to consider the cost of alternative methods of waste treatment and, in evaluating reclamation, to disregard any income received for reclaimed materials. The minimum benefit of separating materials is, therefore, that disposal is at least free. This assumption seems sufficiently conservative to predict that if a reclamation plant can prove to be economically advantageous to a community in these circumstances, in practice and at most periods the profitability will be high.

The two most used methods of treatment of solid municipal waste are dumping and incineration. The costs per ton for treatment (not including collection) vary from about $1.50 to over $20. The lower figure is for a rural community having within its borders spoiled land of no economic or ecological value until it is filled, and the costs are merely for fencing, supervision and bulldozing. It seems probable, and certainly desirable, that open dumps will be outlawed soon in most communities, and the costs for some form of sanitary landfill, about $3.50 per ton, will form the lower limit.

At the other end of the scale are those large cities which have used up all available dumping space within their border, whose neighbors are either outlawing, or charging a high price for, dumping in their territories, and which therefore install incinerators to reduce the mass of material to be dumped to 10 to 20 percent of the initial amount. Incineration costs are from $5.00 per ton for very large (more than 1,000 tons per day) very well run plants to over $20 per ton for small mismanaged plants, and these figures are likely to increase rather than decrease as the costs of improved air pollution control equipment increase. At some point in this cost range, a separation reclamation plant should become competitive even with no income from the salvaged materials.

Examine a hypothetical large throughput separation reclamation plant designed for 600 tons per day input on a two shift, five day per week basis, and actually handling a mean input of 500 tons per day. Suppose that the operating costs are made up of the following:

Labor:	1 manager	$ 25,000 per year	
	1 assistant manager	17,000	
	1 secretary	8,000	
	2 supervisors	30,000	
	2 sorting operators	16,000	
	4 baler operators	40,000	
	2 weight scale clerks	18,000	
	2 bulldozer or crane operators	24,000	
	Total labor	$178,000	
Total labor		$178,000	
Fringe benefits, pensions, insurance		52,000	
Part-time help for sickness, vacations, etc.		30,000	
Total			$260,000
Power costs—assume 150KW mean load at 15 mills per KWH for approximately 4,000 hours per year			9,000
Heating, insurance, maintenance agreements, taxes			14,000
Rapair costs			30,000
TOTAL ANNUAL OPERATING COSTS			$313,000
Operating costs per ton (500 x 5 x 52 tons)			$2.40

These operating costs do not include the disposal charges for the material remaining after separation of salvageable components. These costs should be examined on a parametric basis.

Let the disposal charges be $\$D$ per ton, and let the proportion of input which has to be disposed of as waste be P. If the operating costs are $\$L$ per ton and the capital costs for the plant are expressed **$C** per ton, the criterion that it is better to operate the reclamation plant than to go directly to disposal is:

$$\$L + \$C + P\$S \ngtr \$D$$

$$\text{or } \frac{\$L + \$C}{\$D} \ngtr (1-P)$$

This relation, which is also shown in Figure 1, gives the break-even condition, which would not of course form an attractive risk for private capital. On the other hand, it is highly unlikely that there would be no income from the sale of any of the reclaimed materials. Another unaccounted benefit is that it will probably be easier and cheaper to dispose of the remaining material after paper, cans, textiles and cardboard, for instance, have been removed. To give an example of what may be inferred by the above figure, suppose a plant included some mechanization in the sorting operation and was thereby able to reduce the proportion of material ultimately disposed of to 50 percent, with the above operating costs. If the local disposal charges were $10 per ton and if money for this process could be obtained on the municipal bond market for 5 percent interest, for a 15-year plant life with no salvage value, the break-even capital cost of the plant would be $3.5 million.

Since paper alone accounts for between 50 and 60 percent of municipal refuse, the figure of 50 percent reclamation should not be difficult to achieve. Certainly this is the case if the dirty paper and garbage are composted, as is done by MetroWaste, but the incremental capital and operating costs of the composting operation are

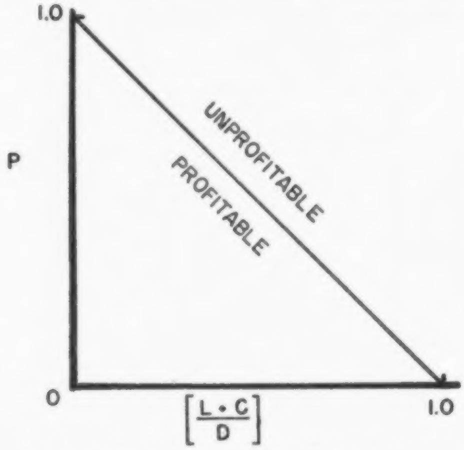

Figure 1: Economics of Reclamation Without Income

high, and the probability of finding a market is low. It should be safe to conclude that in areas where the disposal charges are in the region of $10 per ton and where there is the possibility of aggregating a waste flow of at least 500 tons per day (conditions which are found in many large cities), a sorting and reclamation plant should be profitable even if the market for 'secondary' materials is uncertain.

TABLE 1
Secondary-Material Prices,
Approximate Ranges 1967-1969

Newspaper, clean	$20—30	per ton
Newspaper, soiled	10—20	per ton
Cardboard	5—45	per ton
Ferrous cans	20—25	per ton
Glass cullet, mixed	5—15	per ton
Glass cullet, sorted	10—20	per ton
Aluminum	200—240	per ton
Copper	600—800	per ton

There are examples to indicate that this proviso, based on the assumption that the separated materials will be taken away without payment being made, is too pessimistic. The MetroWaste plant at Houston is reportedly near to breaking even although the amount paid by the city of Houston to MetroWaste is only about $4.25 per ton. In a higher disposal cost area, and with greater automation, profitability should be assured. Sanitary Refuse Collectors of Montreal, as reported by W. J. Johnston,[1] make a profit of $0.57 per ton from salvage by a traditional manual 'picking' procedure from a conveyor belt feeding a grinder.

If income from the sale of separated materials is included in the evaluation, the expression for profitability becomes:

$$\$L + \$C + P\$D - (1-P)\$I \quad > \quad \$D$$

where the mean income per ton of separated material is $I. Table 1 shows recent figures for secondary material prices. If current prices could be used for the value of paper, cans and bottles, a high capital cost plant could be justified in areas where the cost of alternatives is high. Compared with an incinerator, a reclamation plant needs no air pollution control equipment or a stack, and unless very sophisticated sorting equipment is required, the capital cost should be lower than for an incinerator to deal with the same flow (Figure 2).

The importance of reclaiming as high a proportion of materials as possible should be emphasized. If the high cost of installing equipment to handle 600 tons per day of refuse is to be justified, a major portion of this flow must be diverted and must not simply pass out of the plant to be dealt with by normal methods.

After a review of some of the developments in machine assisted and fully mechanized sorting, some suggestions for the design of a municipal reclamation plant will be made.

Machine Sorting

While sorting is essentially one process, in machine sorting there are normally at least two distinct parts of the process: coding and switching.

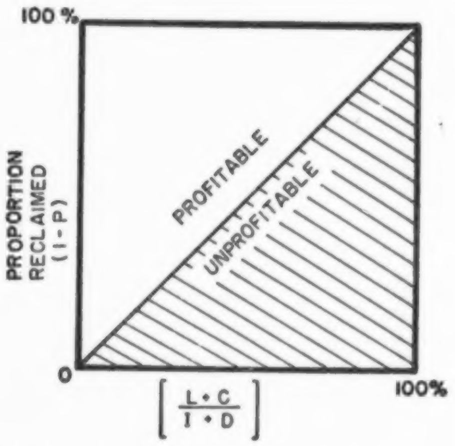

Figure 2: Economics of Reclamation with Income

It has often been suggested that all materials should be coded during manufacture with a tracer which would assist greatly in sorting for reclamation, but no economic or even workable system has yet been proposed. Accordingly there has been vigorous activity in several places to develop specialized equipment to sort mixed municipal trash into its useful and valueless constituents. There have also been developed some highly sophisticated machines for particular purposes, such as the sorting of mining ores or mail and of airline luggage. The inhomogeneity of mixed refuse makes the task of sorting — or even just coding — far more difficult than for such comparatively uniform feeds as ores where the choice to be made is usually binary — is the ore high or low-grade? Is the material coal or shale? Saying this is not to belittle the problems which makers of existing sorting equipment have overcome. However, consider a typical item of refuse - a beer can. It may have a paper label or be painted, may have a steel body and aluminum ends, and may contain some remaining beer or rain may have half-filled it.

A strong magnet may decide that this item is ferrous. A meter sensing surface characteristics only may code it as paper or aluminum, depending on where sensing was carried out. And a sensor measuring attenuation or radiation passing through the can will probably decide that something having so high a water content must be fruit. All this is supposing that the can could be measured alone. It may well have been in a paper or plastic bag, or become entangled in a nylon stocking, or have stuck to it some butter paper.

Faced with problems of this type, two responses are possible. One is to use several sensors or one highly sophisticated sensor which will measure something besides just surface or just bulk properties and to reject any item that indicates properties not consistent with its being homogeneous. There are probably sufficient homogeneous items — for instance, newspaper, magazines, phone books, bottles, cans — in municipal refuse for such an approach to be reasonable and promising.

The second response is to grind everything finely enough so that the majority of the particles are individually homogeneous. They can then be treated individually or in bulk.

Whether the refuse is ground or merely separated into individual items and whether the items or particles are treated individually or in bulk, sensing and switching can be affected in two ways. One is to make successive binary choices until there is an assurance that the sorted products of several branches will be sufficiently pure for full market value of each to be realizable. The purity, or homogeneity, needs emphasis because contaminated materials — paper with plastics; iron with copper; glass with aluminum; cotton textiles with synthetics — fetch a comparatively low price if they are saleable at all (Figure 3).

The principal alternative approach, the multiple-choice series system, is (so far as it is known) being pursued as a fully mechanized system only

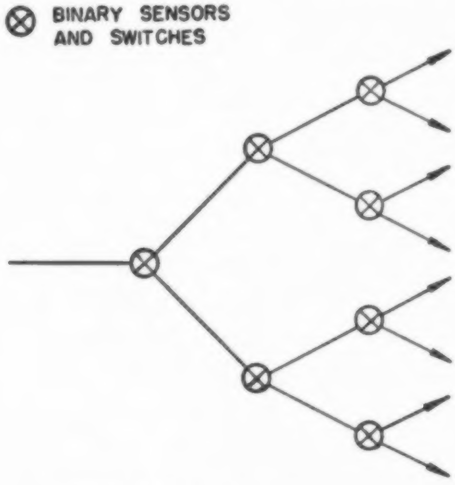

Figure 3: Binary Branched System

at MIT, and a progress report will be made on the investigations. But sorting machines of this type using a human coder have been developed for mail sorting and similar tasks, and it will be suggested that they should have immediate application in reclamation from refuse (Figure 4).

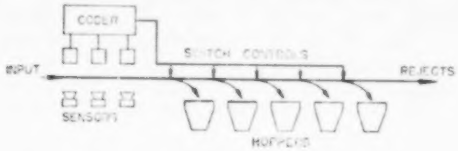

Figure 4: Multiple-Choice Series System

Binary Branched Systems

Magnetic Coding and Sorting

An 'overband' magnetic sorter is often used on the feed to an incinerator or on the ash discharge (when less contaminated material is obtained at the expense of some oxidation) and is of course always part of a reclamation or compost plant. It is usually the only available machinery for automatic coding and sorting (which occur in the same operation).

Color Coding and Air Switching

A machine has been developed by the Sortex Company of North America to sort translucent ore by color. It is being used at the Bureau of Mines to sort glass fragments into flint glass and colored glass, and by appropriate use of filters a series of such machines could sort glass into the four principal colors of bottle glass. The glass pieces of roughly uniform size (obtained by initial screening) are fed from a hopper to a vibrating table and thence to a grooved belt moving at 5 to 10 fps. As the pieces fall from the end of the belt, each one is sensed by three photocells appropriately filtered, and the smaller fraction, colored or uncolored, is diverted by rapid acting air blasts to separate hoppers (Figure 5).

Conductivity Coding and Air Switching

Instruments which sense the change of electric field strength when a conductor is moved through the field can, as with mine detectors, discriminate between metals and nonmetals. So far as is known, such instruments have not been used in refuse reclamation plants for two reasons. Firstly, they code only, and sorting and switching mechanisms would have to be designed just for this one operation. Secondly mixed non-ferrous metals are of little value; means would have to be developed to separate copper from brass from aluminum and so on. It may be inferred from descriptions below of other processes that means might in fact now be available.

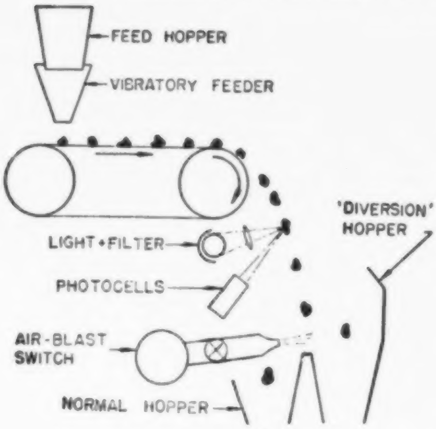

Figure 5: Sortex Company Color Sorter

Automatic sorting by direct measurement of conductivity has been developed to an advanced stage in the ore machinery industry. Figure 6 shows diagrammatically a machine produced by Ore Sorters (Canada) Limited, a subsidiary of Rio Tinto Zinc Corporation, in which the feed is distributed on to, and falls down, a 48 inches wide angled slide. One or more of a series of electrodes carrying a steady potential with respect to the grounded slide make contact with each particle, and the current through the particle enables it to be coded as 'high' or 'low' conductivity. As the pieces fall off the end of the slide, air blasts divert either the high or low conductivity pieces, whichever is in the lower proportion.

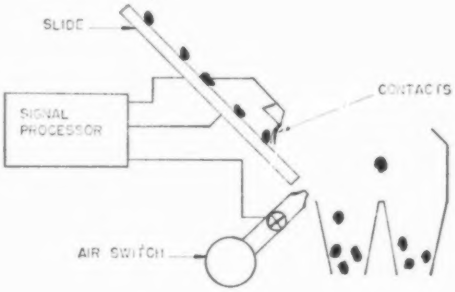

Figure 6: RTZ Ore Sorters(Conductivity Sorter)

Photometric and Radiometric Coding and Air Switching

Ore Sorters Ltd. has also developed machines which sort on the basis of surface reflectance of a scanning laser spot, and of radioactive properties. The photometric unit may be of value in application to mixed refuse, and it is hoped that trials will be made. A random-feed stream is distributed on a horizontally moving conveyor belt and is scanned by a laser spot reflected from a rotating mirror (Figure 7). A photomultiplier measures the characteristics of the reflected light, and an analyzer determines whether or not appropriate air jets should be actuated to divert each piece.

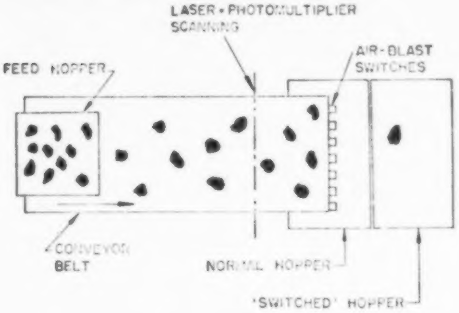

Figure 7: RTZ Ore-Sorters Ltd. (Photometric Sorter)

X-Ray-Attenuation Coding and Mechanical Switching

Another industry which has developed coding and sorting machinery to a high degree is the agriculture and food industry. An example of the use of x-rays for coding is shown by a machine conceived by a Scottish farmer for separating potatoes from stones and dirt. The principle is similar to that of the two belt sorters just described except that switching is by movable fingers rather than by air blast.[2] (Figure 8).

Sorting by Density and Drag

A machine developed also for the food industry, principally for the sorting of food beans, has been applied by Stanford Research Institute to the separation of mixed municipal refuse.[3] The so-called air classifier consists of a zigzag duct arranged with its principal axis vertical (Figure 9). Air is drawn off from the top and the mixed material is fed into the duct at an intermediate point. Pieces with a combination of low density and high drag are entrained into the rising air stream, while the heavier or lower-drag pieces descend. It is claimed by Stanford Research Institute that components having densities only a few percent apart can be successfully and economically sorted. If this claim is substantiated, the machine could obviously have a very beneficial impact on the reclamation picture. This type of machine requires the input to be pulverized, dried and screened so that any one classifier is fed with pieces varying in size by only a small degree.

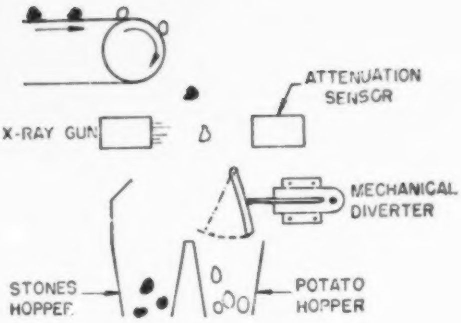

Figure 8: Niae X-ray Potato Sorter

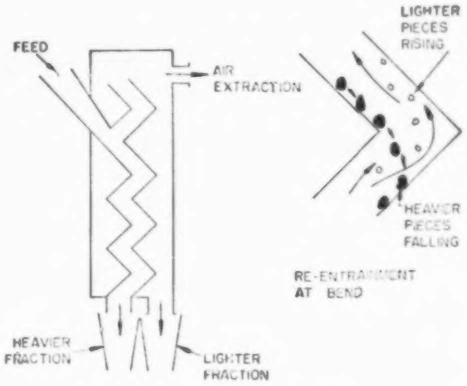

Figure 9: SRI Zig-Zag Air Classifier

A fluidized-bed separator has been adapted for shredded (particle size over 10 mesh) refuse at the Warren Spring Ministry of Technology Laboratory in Britain.[4] Air is supplied to several sections of a porous-bronze table which is vibrated. A size-selected fluidizing medium, in this case ferrosilicon or magnetic or iron powder, is kept in suspension and recirculated, the feed particles being larger than those of the medium so that screening can be used. The denser particles, which sink to the bottom of the bed, are moved by the vibrating table up the bed, while the lighter feed particles float on the top of the bed. This unit has been installed in a pilot plant. Operating costs of 25-50 cents per ton have been forecast, including depreciation (Figure 10).

The Franklin Institute has claimed to have produced a machine which sorts municipal refuse but has not released details other than a news item which hints at the device being a binary separator based on density.

Sorting by Froth Flotation

The Bureau of Mines is recovering metals, principally, from incinerator residue by an ore-beneficiation process.[5] This is a branched binary scheme, involving successive grinding, size segregation by screening, and separation by surface properties in froth flotation. Again, if the projected economics are proven accurate, this process could be very significant.

Sorting by 'Bounce'

A well-established method of sorting hard from soft materials is to allow a stream to fall on to a moving and perhaps vibrating belt (Figure 11).

Soft materials are carried away by the belt. Hard materials bounce off the belt into a hopper. This type of arrangement is used by MetroWaste to separate the larger ground-glass particles from compost.

Sorting by Pulping

A method of separation which has reached the pilot-plant stage is called the 'Hydropulping' process of the Black-Clawson Company, manufacturers of paper-making machinery. By passing all municipal refuse into a little-modified pulping tank in which pumps and impellers induce a strong vortex and associated mixing and tearing, the paper products break down and are recovered by filtering the resulting pulp through a succession of perforated-screen and slotted classifiers. A 5/8-inch-diameter-hole screen is used first to take out the glass, cans and so forth, and subsequently a screen with 1/8-inch-diameter-holes and another with 0.014-inch slits are used to select fibers and to reject flakes, rubber-like balls (from, for example, pressure-sensitive adhesive backings) and pieces of plastic film. Subsequently a close screen (150-mesh wire) is used to retain the desired fibers and to reject the fines. The fiber is dewatered and thickened and baled for use in a paper mill.

The ferrous cans are recovered magnetically and the glass from bottles broken in the pulper is screened out.

The Black-Clawson process is thus a complete binary branched system. (There are additional binary sorters on the metal and glass branches designed to yield products with as little contamination as possible). Over 50 per cent of the incoming feed is sorted into reclaimable materials. Including income from these products, economic predictions made by Black-Clawson are for refuse-treatment costs of 70 cents per ton for a 500-tons-per-day plant and a net income of 90 cents per ton if the volume is 1,000 tons per day. If these projec-

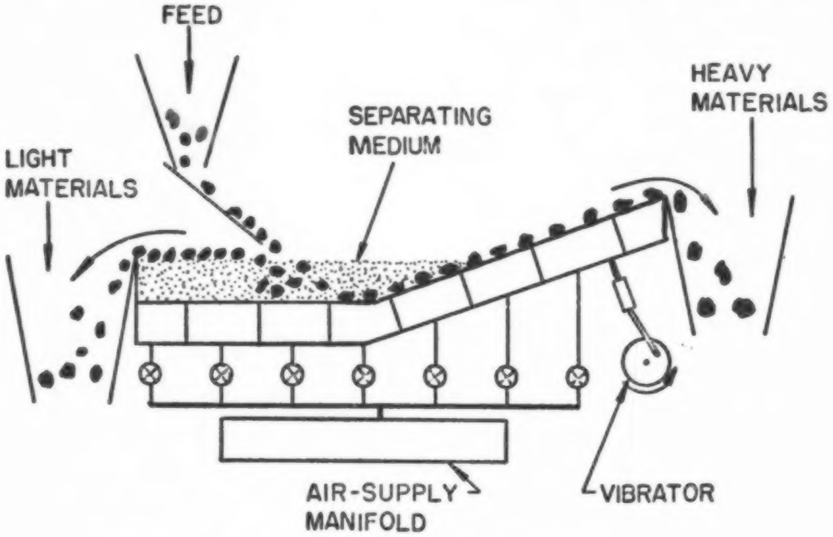

Figure 10: Warrens Spring's Fluidized-Bed Classifier

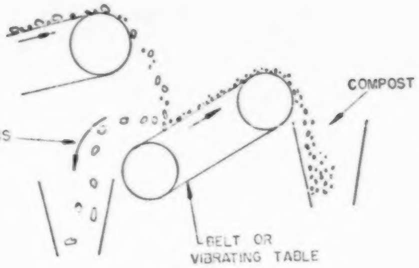

Figure 11: Glass Separator

tions are borne out in practice, the whole solid waste picture would be transformed, and steady markets for secondary pulp, glass cullet and cans would need to be assured.

Multiple-Choice Sorting

Before reviewing some approaches in fully mechanized sorting, some existing machinery involving human coding which would seem to have immediate application to refuse sorting will be briefly described. A great deal of work has been and is being carried out into automating post-office sorting[6] and that connected with airport baggage handling.[7] Occasionally the coding is done before the pieces enter the stream, as, for instance, when the airline booking clerk attaches a punched or magnetically marked card to a piece of luggage.

These sorting systems consist of human coding and mechanical switching because no coder having capabilities approaching those of our eyes and brains has been devised. There seems no reason why such a system should not prove to be likewise advantageous for sorting mixed municipal waste. One method would be pictured in Figure 12.

Manual Coding, Machine Switching

The refuse would be fed on to a moving belt by conventional arrangements, and an 'overband' magnet would remove ferrous material for baling. A vibrating sieve would then allow all pieces smaller than a quart soda bottle to drop away for disposal. The remaining large items would be fed to a fast-moving belt in such a way that each item is separated from the next by an empty space of belt. (This again is regularly done in materials handling, though the highly nonhomogeneous nature of mixed refuse will undoubtedly require special treatment to be used.) This belt would pass in view of an operator at a coding station who would have before him a console having buttons, one for each component of refuse to be sorted. By pressing an appropriate button as each piece of refuse appeared, the operator would code a magnetic 'stripe' on the underside of the belt or on a magnetic tape geared to the belt. If the code indicated 'glass' — or even if the economics indicated that it is worth sorting glass by color, 'green glass' — the coding would later actuate an appropriate diverter to sweep the glass into a hopper. Most likely the glass would be ground or it might be sorted by color mechanically before being ground or whole bottles might be separated for return to the bottlers if the incremental value justified the operation.

In any event, the productivity of the human sorter is increased 5 to 10 times by this mechanical assistance. Furthermore, it becomes easier to hire reliable operators when a white-collar environment can be offered, and it is justifiable to pay a higher reward in addition to an incentive bonus based on reclaimed value of materials. It seems probable that this type of plant will form an intermediate step before full machine coding and sorting is practicable.

M.I.T. Studies

In reviewing the initial work which has been carried out at MIT into multiple-choice sorting since the summer of 1969, we should like to make a further breakdown of the various approaches investigated into three categories: sorting by sensing different values of a single property in the vortex classifier; by sensing the values of several (the series-sensor system); or by sensing a combination of properties (the signature system).

The Vortex Classifier

This machine, which has its counterparts in the centrifugal separators of chemistry and medicine, sorts in one operation by sensing a combination of density and drag, as for the zigzag classifier. However, instead of the input stream being separated into two streams of 'high' and 'low' density, the material is distributed in a continuous manner over a range of density-drag combinations (Figure 13). The principle of operation is this: particles are allowed to reach an equilibrium position in a radially inward-flowing vortex. The radially inward component of the flow produces a drag force on the particle which depends on the shape and size of the particle and on the square (approximately) of the inward flow velocity. This velocity increases as the radius is reduced, the variation being dependent on the shape of the vortex chamber. The drag gives a centripetal acceleration to the particle which in equilibrium conditions will be moving in a circular path with no relative velocity to the tangential component of the flow.

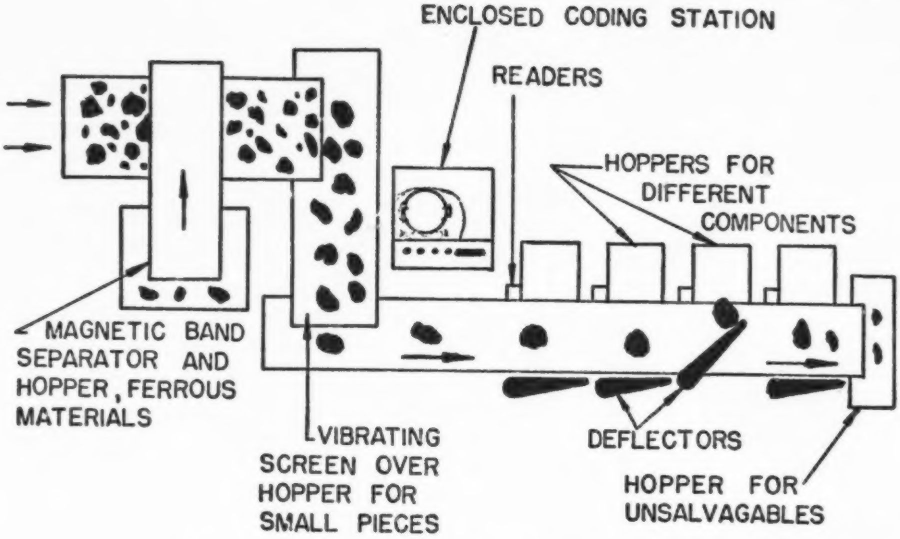
ENCLOSED CODING STATION
READERS
HOPPERS FOR DIFFERENT COMPONENTS
MAGNETIC BAND SEPARATOR AND HOPPER, FERROUS MATERIALS
VIBRATING SCREEN OVER HOPPER FOR SMALL PIECES
DEFLECTORS
HOPPER FOR UNSALVAGABLES

Figure 12: Manual-Coding, Machine-Switching, Multiple-Choice Sorter

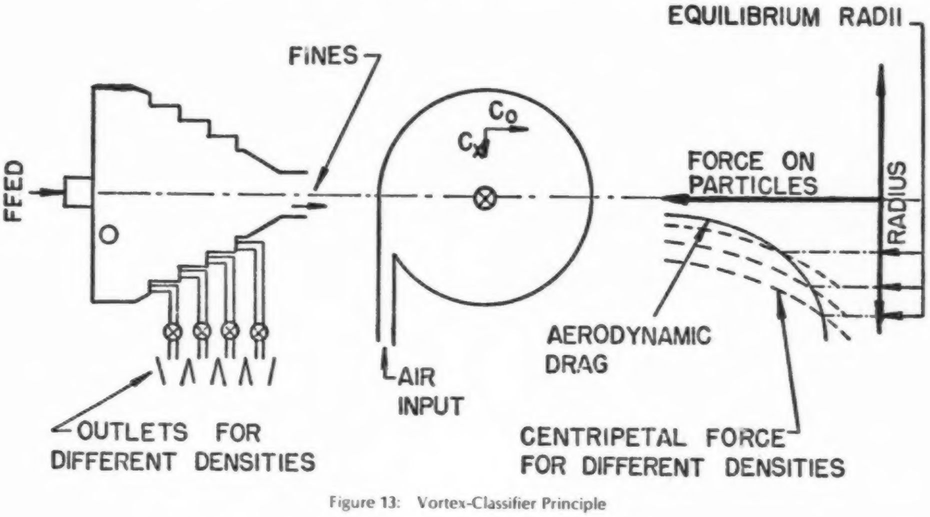
EQUILIBRIUM RADII
FINES
C_o
C_r
FEED
FORCE ON PARTICLES
RADIUS
AERODYNAMIC DRAG
AIR INPUT
OUTLETS FOR DIFFERENT DENSITIES
CENTRIPETAL FORCE FOR DIFFERENT DENSITIES

Figure 13: Vortex-Classifier Principle

It can be shown that the equilibrium radius is given by:

$$\frac{r}{d} = \frac{4}{3}\left(\frac{P_p}{P_g}\right)\left(\frac{C_o}{C_r}\right)^2 \frac{1}{C_d} \quad \text{for spherical particles,}$$

where
r = radius of path
d = particle diameter
P_p = particle density
P_g = gas density
C_o = tangential gas velocity
C_r = radial gas velocity
C_d = drag coefficient of particle

(The ratio (C_o/C_r) is a function of radius and the design of classifier chamber.)

It should be possible to affect a high degree of separation of materials on a density-drag basis providing that the shape and size of the particles are similar. This condition would be met by prior milling and screening.

Preliminary experiments have shown that a high degree of separation of aluminum foil from paper and plastics was achieved but with particles which were not necessarily of similar size and shape (the particles were produced by a foregoing vortex pulverizer). Model studies are being continued to determine flow patterns, particle interactions and the effects of shape before attempting a prototype design.

Multiple-Choice Series System

In these systems outputs from a variety of sensors are analyzed by a central logic unit and a sorting decision made upon the basis of the total input. Such a system is referred to as a series system (Figure 4). The number of sensors involved is a function of the number of sorted categories desired, efficiency of sorting desired, and the amount and accuracy of information available from each sensor. In Figure 12, each sensor will provide an analog output corresponding to a physical property, or composite of physical properties, of each piece of refuse. The logic unit is charged with analyzing the sensor outputs so as either to identify a piece of refuse or to reject it as non-classifiable. In addition, the logic unit must perform the synchronizing function of keeping track of each refuse particle as it passes through the sensor line so that if sensor A views particle X at time t, then at time t +Δ t (where Δ t is the time required for particle X to progress from sensor A to sensor B), the output of sensor B will be interpreted as belonging to particle X instead of to some other particle. If the refuse flow system operates at constant speed, as in a conveyor-belt system, the problem is greatly simplified. If a situation occurred such that the output from sensor could be zero for some particular refuse item, a separate system might be needed to synchronize the sensors and the switches with the progress of the particle.

Many different sensors have been under investigation for possible use in the series system. One concept is that of the "total spectrum" approach. In one example of this technique, a series of sensors detect the interaction of the particle with electromagnetic fields. These sensors may span many decades of wavelength, from radio frequencies to the visible region.

In the experiment (Figure 14), materials passed between the transmitter and the receiver horns of a 3-cm-wavelength microwave system. As might be expected, the signal attenuation was greatly dependent on the material passing between the horns: at the wavelength used, metals appeared opaque, glasses mostly transparent, and papers and textiles partly transparent. This information alone is not sufficient for coding, however, because a thick sample of glass can produce the same attenuation as a thin sample of aluminum. Moisture in the paper has a similar attenuating effect. One might use water-absorbency to aid in coding. Materials might be passed through a controlled-humidity environment, then examined by

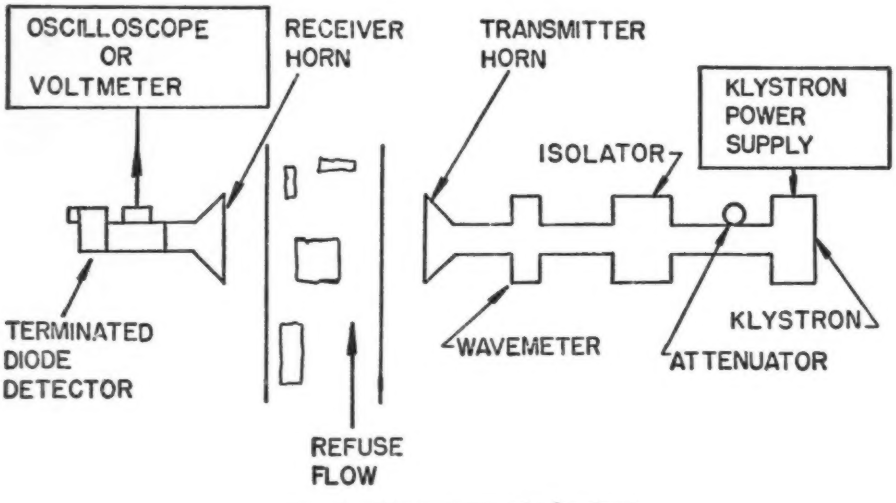

Figure 14: Microwave-Attenuation Experiment

the microwave technique, resulting in a measurement of their water absorbency. The samples will be viewed at several wavelengths to try to eliminate the thickness dependence of the measurements.

Research plans also include investigating infrared, optical and spectrographic sensors. Ideally with infrared, spectral scanning would be used; but in the interests of simplicity and economy, it may be better to use a discrete-wavelength system. Either monochromatic infrared sources of several wavelengths or monochromatic detectors could be used in the infrared sensor. Transmission, reflection, or emission techniques could be used, the first two being active techniques and the last passive. The emission approach consists of heating each sample to some temperature and then viewing the relative intensities of infrared radiation emitted from the sample at different wavelengths.

Additional information would be given by finding the rate of fall of temperature, which would be a function of the conductivity. And transmission and reflection techniques combined would give even more coding information. This method consists of passing each sample past a source and measuring the relative intensities at various wavelengths of reflected and transmitted energy. In effect, this is the same as seeing the sample through eyes sensitive to infrared.

Additionally, an optical sensor is proposed which is similar to the infrared sensor, except that optical wavelengths are used. (This arrangement would then be similar to the RTZ Ore Sorters photometric sorter with several laser scanner-detector units.) This total-spectrum approach might be sufficient in itself as a sensor system or might be combined with other techniques to form the complete sensor series. Again, the principle problems are to eliminate surface condition, attitude and geometry in coding from surface reflection and emission, and to eliminate attitude and thickness in coding from transmission measurements. It is believed that the combination of signals from several sensors operating sequentially on a single sample will enable these problems to be overcome.

Another proposed sensor which includes some of the total-spectrum ideas is a device wherein a high-power pulsed laser beam vaporizes part of a refuse object. The flowing vapor would then be subjected to spectroscopic analysis. The analysis could either be of the scanning variety or of the discrete-wavelength type previously discussed. In either case, analysis would have to be very rapid, but this sensor technique holds the promise of providing a large amount of information. Similar flame photometry methods as used in laboratories are capable of providing highly accurate chemical analyses of substances.

Signature Systems

Whenever the output of a sensor is a continuous function analogous to some property or combination of properties of a material the output is referred to as a 'signature'. An experiment with the signature system is shown in Figure 15 and it is believed to be a viable technique. An impact tool rigidly attached to an accelerometer, all of which is connected to a pivoting arm, is dropped onto a sample. The resulting impact signature is a time-dependent voltage output from the accelerometer representing the deceleration forces generated when the impact tool deforms the sample. It is clear from visual examination of Figures 16 - 18 that quite different signatures result from impacting different materials.

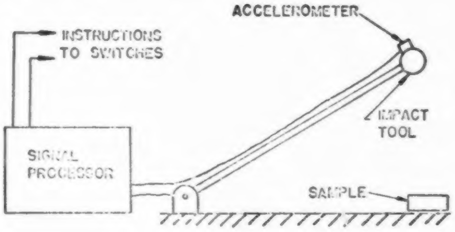

Figure 15: Impact-Signature Device

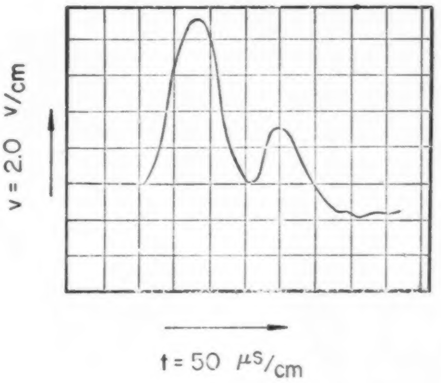

Figure 16: Impact Signature of Aluminum Plate

Coding Logic Needed with the Signature System

Having obtained a signature, in this case from an impact device, but in general from any sensor, the next problem is to automatically process the information so as to make a sorting decision. Assuming a set of inputs to affect classification into several categories, there are essentially two methods of building a 'black box' to handle the decision-making task. The first method is to utilize a heuristic computer program in which the identity of the sample is known. Every correct identification made by the program would result in a redistribution of priority-weighing functions among the various algorithms in the program, reinforcing the algorithms responsible for making the correct identification. In this fashion the program would 'learn' until an optimum efficiency point was passed. The computer itself could be connected to the sorting system, but this seems needlessly complicated, as after the program has 'learned' to sort, the analytic algorithms found to be used in identification could be wired into a relatively simple 'black box' of electronic hardware. In this fashion the characteristics of a signature which make it useful or perhaps unique can be found and used.

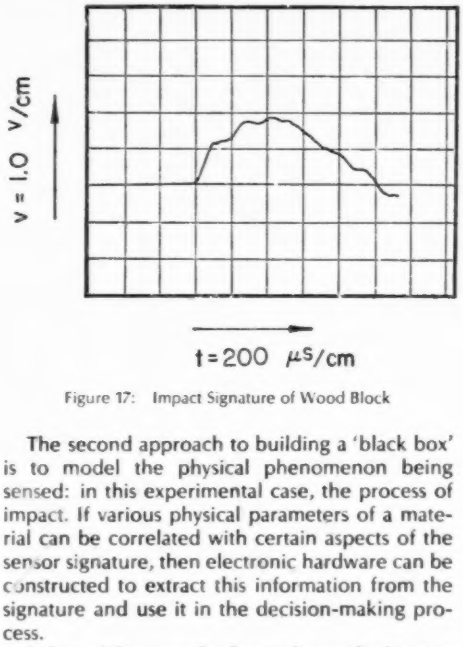

Figure 17: Impact Signature of Wood Block

The second approach to building a 'black box' is to model the physical phenomenon being sensed: in this experimental case, the process of impact. If various physical parameters of a material can be correlated with certain aspects of the sensor signature, then electronic hardware can be constructed to extract this information from the signature and use it in the decision-making process.

Either of these methods may be applied to our experimental approach. Certain properties of the impact signature have been chosen as possible functions of physical properties, and instrumentation is being constructed to extract this information. Given the accelerometer output as a time-varying voltage, the chosen parameters are peak initial slope, time to peak voltage, and time to the first zero crossing of the voltage trace across the time axis. A block diagram of the circuitry to be used is shown in Figure 19. Simplified schematic versions of the block components are also shown.

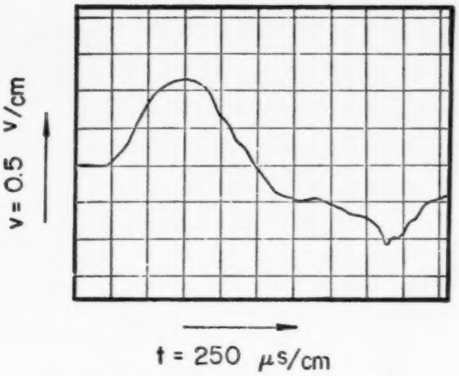

Figure 18: Impact Signature of Stacked Paper

The output voltage from the accelerometer is fed to a sample-and-hold circuit, a comparator, and a differentiator. The sample-and-hold circuit retains the peak value of the voltage across a capacitor. This voltage is analogous to the peak deceleration. The comparator, which in this case compares the input to a zero reference voltage, functions essentially as an amplifier. When the accelerometer output increases above zero, the comparator output rapidly rises to its saturation output level, and cuts off when the accelerometer output approaches zero. The resulting square wave is integrated into a ramp function, the end height of which is a voltage analog to the time to the first zero crossing of the signature.

The differentiator, together with duplicates of the previously mentioned circuitry, produce voltages analogous to the peak initial slope and the time to peak deceleration. (For clarity, reset provisions on the sample-and-hold and integrator circuits are not shown.) It is necessary to return each analog voltage to zero value before the system is ready to receive the accelerometer trace from another sample.

After all the analog voltages become available, it is necessary to use some sort of real-time processor in which the analog information is compared to that contained in a table. The impact information may be combined with information from other sensors to indicate the locus of the identity of the material in question in a multi-dimensional array contained in the processor. Ulti-

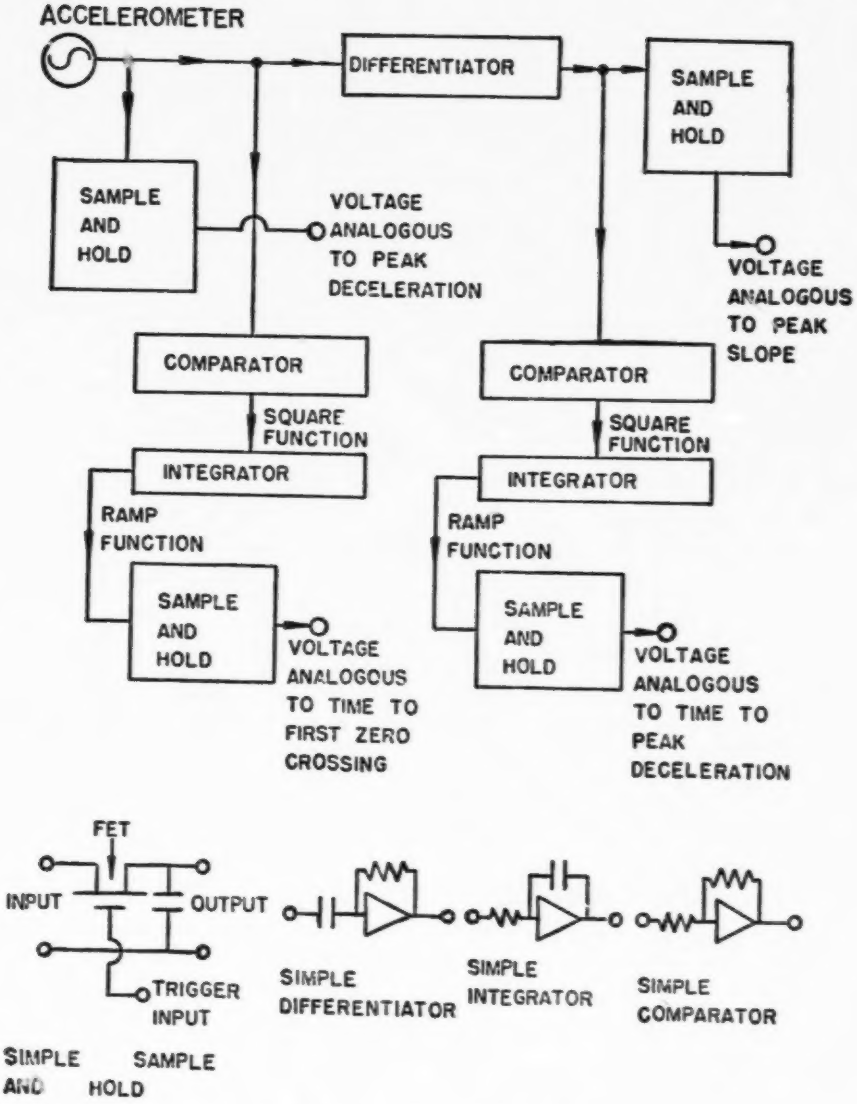
ACCELEROMETER
DIFFERENTIATOR
SAMPLE AND HOLD
SAMPLE AND HOLD
VOLTAGE ANALOGOUS TO PEAK DECELERATION
VOLTAGE ANALOGOUS TO PEAK SLOPE
COMPARATOR
COMPARATOR
SQUARE FUNCTION
SQUARE FUNCTION
INTEGRATOR
INTEGRATOR
RAMP FUNCTION
RAMP FUNCTION
SAMPLE AND HOLD
SAMPLE AND HOLD
VOLTAGE ANALOGOUS TO TIME TO FIRST ZERO CROSSING
VOLTAGE ANALOGOUS TO TIME TO PEAK DECELERATION
FET
INPUT
OUTPUT
TRIGGER INPUT
SIMPLE SAMPLE AND HOLD
SIMPLE DIFFERENTIATOR
SIMPLE INTEGRATOR
SIMPLE COMPARATOR

Figure 19: Block Diagram of Signature Processor

mately, it is desirable to improve accuracy by reducing the 'noise' as far as possible, and this would be helped by using digital processing. Figure 20 represents the identification of a material in a two-dimensional property table, Array S. If, for example, two sensors gave outputs S_{kj} and S_{lk}, then the material has been definitely identified as material. If two sensors present outputs S_{jm} and S_{kl}, then the identification is ambiguous and the sensors must be refined and/or weighted, or more sensors added and weighted.

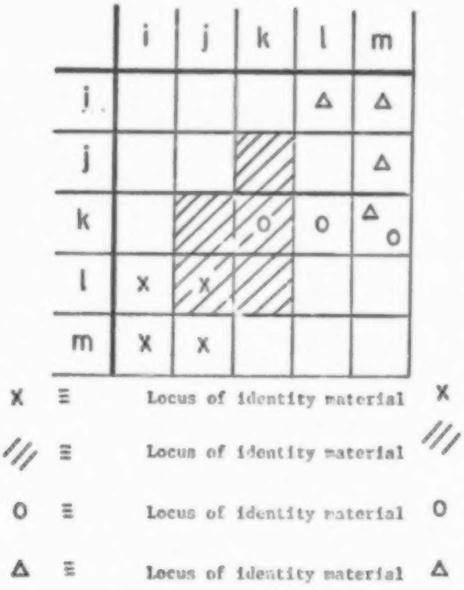
i
j
k
l
m
X ≡ Locus of identity material X
/// ≡ Locus of identity material ///
O ≡ Locus of identity material O
Δ ≡ Locus of identity material Δ

Figure 20: Two-Dimensional Property Array 5

Evolutionary Municipal-Refuse Reclamation Plant

It is the author's opinion that reclamation plants could be profitable now in areas where the costs of alternative disposal are in the region of $10 per ton, and possibly in lesser-cost regions. The series system with manual coding and mechanical switching uses near-conventional technology and offers the greatest promise of repaying the investment. Such a system would also permit evolutionary development. For instance, automatic coders could be tried out to replace the human coder without the risk of the plant being useless if the automatic coder did not come up to specifications. Then other equipment could be installed to try to recover material from the large proportion which will be initially sieved out as being too small or which will be rejected because of human uncertainty or because of a heterogeneous composition. These streams could be pulverized and sorted by one of the several bulk classifiers being developed. This arrangement would reduce the load on the pulverizer — always expensive in terms of maintenance and power requirements — by removing the large reclaimable items and also the bed springs, rocks, engine blocks and the like which cause problems in pulverizers.

REFERENCES

1. Johnson, W. J. "Refuse-Reduction Plant, Montreal-Quebec." *Engineering Journal*, June 1969.

2. "Potatoes Harvested by X-rays." *Science Journal* (London), January 1970.

3. Boettcher, Richard A. "Air Classification for Reclamation Processing of Solid Wastes." ASME Paper 69-WA/PID-9, 1969.

4. Douglas, E. "Public Cleansing," London, Vol. LX, No. 1, January 1970.

5. Stanczyk, M. H. and Ruppert, J. A. "Continuous Physical Beneficiation of Metals and Minerals Contained Incinerator Residues." Second Mineral-Waste-Utilization Symposium, IIT Research Institute, Chicago, Ill. 60616, March 19, 1970.

6. McKenna, M. L. "Sorting Technology and Its' Application to Materials Management." ASME Paper 69-MH-14, 1969.

7. Goldstein, K. S. "Telecar Baggage System-Automation in Action." ASME Paper 69-WA/MH-2, 1969.

Continuous Physical Beneficiation of Metals and Minerals Contained in Municipal Incinerator Residues

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United States Department of the Interior

INTRODUCTION

With the passage of the Solid Waste Disposal Act, the Bureau of Mines initiated several in-house research programs to develop new and improved methods of proper and economic solid waste disposal. The program being carried out at the Bureau's College Park Metallurgy Research Center is concerned with eliminating the current waste of valuable materials in urban refuse by developing low-cost methods for reclaiming and recycling the metal and mineral values contained in municipal incinerator residues.

The Bureau's initial research established reliable methods for sampling incinerator residues and characterizing these wet complex mixtures of metals and minerals. The work revealed that metal and glass account for approximately 75 percent of the residues by weight, a proportion that varied little from sample to sample when considering the heterogeneous character of residues.[1 2]

Upon establishing the general composition of residues, research was then focussed on developing wet mechanical methods for recovering and separating the residues into fractions that, if necessary, could be further treated to produce products suitable for recycling. Relying exclusively on existing mineral engineering technology, various combinations of mineral beneficiation techniques were investigated. The most promising procedures which evolved from this research were incorporated into a continuous mechanical beneficiation plant.[3,4] The plant, designed to process 1,000 pounds of incinerator residues per hour, was constructed for the purpose of developing engineering data to permit design of a plant with a capacity of 250 tons of residues per day, and an evaluation of the capital and operating costs. This report describes the process flowsheet and the results of continuous processing tests.

The Flowsheet

Incinerator residues are a soaking-wet complex mixture of metals, glass, slag, charred and unburned paper, and ash containing various mineral oxides. The moisture content of residues will range from about 22 to 47 percent and is primarily dependent on the degree of burnout, and the type of quenching used at each incinerator. As all incinerator operators are aware, the degree of burnout is largely influenced by such factors as the moisture content of the incoming refuse, operating temperature, the capacity at which the furnaces must operate, and the type and state of repair of the furnaces. It should be pointed out that the process flowsheet incorporated into the continuous processing plant was designed on the basis that the residues would contain a minimum of unburned paper, rags and organic matter.

Residue samples were collected in tarred 30-gallon drums according to procedures developed earlier.[5] These were brought back to the laboratory and weighed. A continuous feeding system was simulated by dumping the wet residues on a large metal apron and raking the material to a feed conveyor at a predetermined rate.

Figure 1 depicts the present process flowsheet incorporated in the continuous processing plant.

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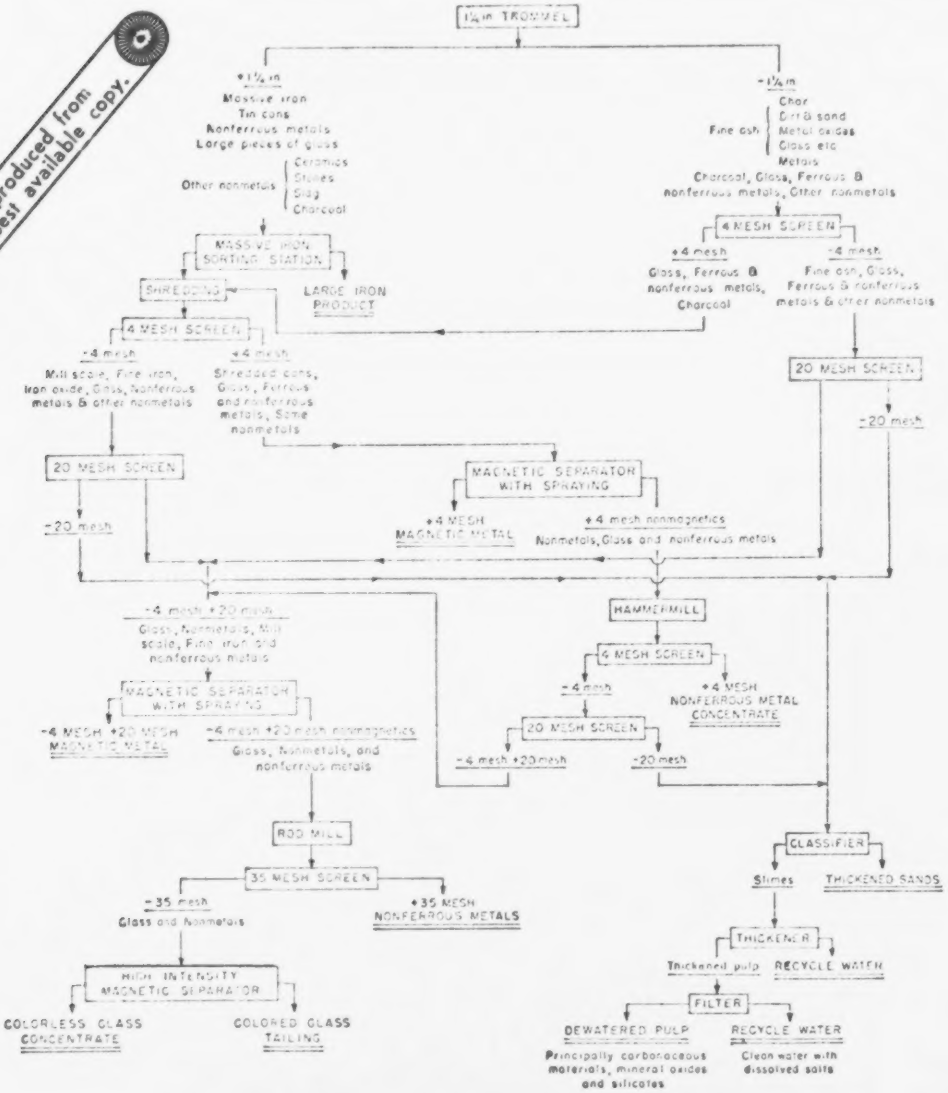
1¼ in TROMMEL
+1¼ in
Massive iron
Tin cans
Nonferrous metals
Large pieces of glass
Other nonmetals
Ceramics
Stones
Slag
Charcoal
-1¼ in
Fine ash
Char
Dirt & sand
Metal oxides
Glass etc
Metals
Charcoal, Glass, Ferrous & nonferrous metals, Other nonmetals
4 MESH SCREEN
+4 mesh
Glass, Ferrous & nonferrous metals, Charcoal
-4 mesh
Fine ash, Glass, Ferrous & nonferrous metals & other nonmetals
MASSIVE IRON SORTING STATION
SHREDDING
LARGE IRON PRODUCT
4 MESH SCREEN
-4 mesh
Mill scale, Fine iron, Iron oxide, Glass, Nonferrous metals & other nonmetals
+4 mesh
Shredded cans, Glass, Ferrous and nonferrous metals, Some nonmetals
20 MESH SCREEN
-20 mesh
20 MESH SCREEN
-20 mesh
MAGNETIC SEPARATOR WITH SPRAYING
+4 MESH MAGNETIC METAL
+4 mesh nonmagnetics
Nonmetals, Glass and nonferrous metals
-4 mesh +20 mesh
Glass, Nonmetals, Mill scale, Fine iron and nonferrous metals
MAGNETIC SEPARATOR WITH SPRAYING
-4 MESH +20 MESH MAGNETIC METAL
-4 mesh +20 mesh nonmagnetics
Glass, Nonmetals, and nonferrous metals
HAMMERMILL
4 MESH SCREEN
-4 mesh
+4 MESH NONFERROUS METAL CONCENTRATE
20 MESH SCREEN
-4 mesh +20 mesh
-20 mesh
ROD MILL
35 MESH SCREEN
-35 mesh
Glass and Nonmetals
+35 MESH NONFERROUS METALS
HIGH INTENSITY MAGNETIC SEPARATOR
COLORLESS GLASS CONCENTRATE
COLORED GLASS TAILING
CLASSIFIER
Slimes
THICKENED SANDS
THICKENER
Thickened pulp
RECYCLE WATER
FILTER
DEWATERED PULP
Principally carbonaceous materials, mineral oxides and silicates
RECYCLE WATER
Clean water with dissolved salts

Figure 1: Continuous Incinerator Residue Processing Plant Flowsheet

Figure 2 is a pictorial form of the circuit presenting the various types of equipment used. The first processing step, after the feeding arrangement, consists of screening in a 3-foot diameter by 10-foot long punched plate trommel screen having 1¼-inch holes. The trommel screen is fitted with internal lifters to achieve a tumbling action. During screening the residues are sprayed continuously with water. The material scalped off by the trommel is composed primarily of cans, wire, large iron, and some large pieces of nonferrous metal, paper, glass and some other nonmetals. The minus 1¼-inch material is screened and washed on a 30-inch diameter circular vibrating screen fitted with both 4- and 20-mesh screens. The plus 4-mesh material consists principally of bottle caps, nails, glass, nonferrous metals and other nonmetals. The minus 4-plus 20-mesh fraction contains glass, other nonmetals, mill scale, fine iron and nonferrous metals. The minus 20-mesh material is composed principally of carbon, dirt, some fine glass, other nonmetals and metal oxides.

All of the plus 1¼-inch material, with the exception of the more massive pieces of iron, is blended with the minus 1¼-inch plus 4-mesh fraction. This composite from the primary screening operation is then shredded in a 30-HP hammermill having 32 swing hammers rotating at a peripheral speed of about 8,500 fpm. The hammermill is fitted with discharge grate bars having 4-by-4-inch openings. The shredded material is transferred to a scondary screening operation where it is washed on a 30-inch diameter vibrating screen fitted with both 4- and 20-mesh screens. The plus 4-mesh oversize material is discharged to a vibrating conveyor which spreads the material and underfeeds a 30-inch diameter by 14-inch wide alternating pole, permanent magnet drum-type separator. The magnet has a field strength of about 500 gauss measured 2 inches from the shell. A water spray gives the material adhering to the magnet a final wash, leaving a clean iron product. The non-magnetic fraction, which is composed of relatively large pieces of nonferrous metal, glass, and other nonmetals, is dewatered on an inclined 20-mesh wedge-slot screen. To recover the nonferrous metals, the plus 20-mesh fraction is fed to a 7.5-HP hammermill having 20 swing hammers rotating at a peripheral speed of about 8,500 fpm. The hammermill, which is fitted with only one 2-inch by 8-inch discharge opening, breaks up most of the glass and other nonmetals. The hammermill discharge is screened and washed on a 24-inch diameter circular vibrating screen fitted with both 4- and 20-mesh screens. The plus 4-mesh material is recovered as a nonferrous metal concentrate. This fraction represents about 75 percent of the recoverable nonferrous metals.

The minus 4-plus 20-mesh product from the primary screening section is combined with the

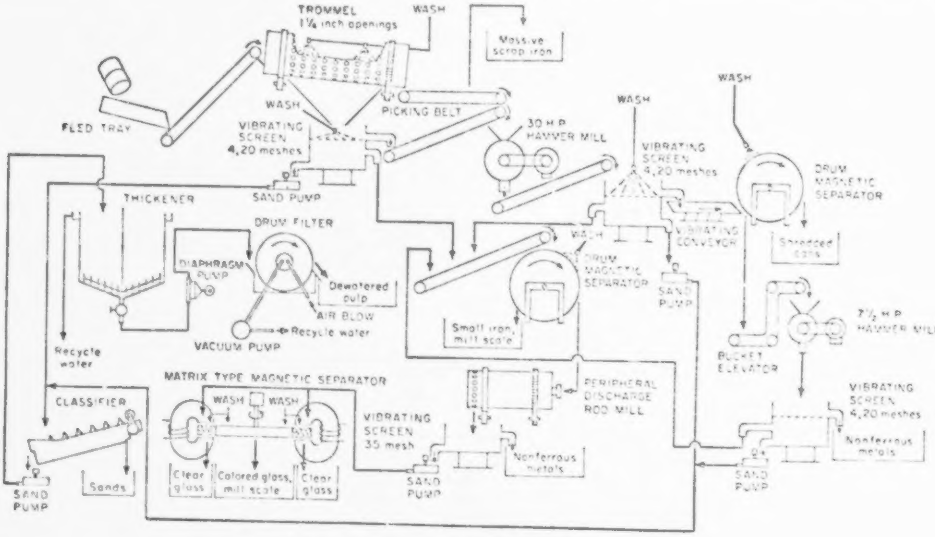
TROMMEL
1¼ inch openings
WASH
Massive scrap iron
WASH
WASH
FEED TRAY
WASH
PICKING BELT
VIBRATING SCREEN 4,20 meshes
30 H.P. HAMMER MILL
VIBRATING SCREEN 4,20 meshes
DRUM MAGNETIC SEPARATOR
THICKENER
SAND PUMP
DRUM FILTER
WASH
VIBRATING CONVEYOR
Shredded cans
DIAPHRAGM PUMP
Dewatered pulp
DRUM MAGNETIC SEPARATOR
SAND PUMP
AIR BLOW
Recycle water
VACUUM PUMP
Small iron, mill scale
7½ H.P. HAMMER MILL
Recycle water
BUCKET ELEVATOR
MATRIX TYPE MAGNETIC SEPARATOR
PERIPHERAL DISCHARGE ROD MILL
CLASSIFIER
WASH
WASH
VIBRATING SCREEN 35 mesh
VIBRATING SCREEN 4,20 meshes
Nonferrous metals
Nonferrous metals
SAND PUMP
Sands
Clear glass
Colored glass, mill scale
Clear glass
SAND PUMP
SAND PUMP

Figure 2: Continuous Beneficiation Plant Circuit

minus 4-plus 20-mesh fractions from both shredding operations. Using an overfeed system, this combined product is treated in a 30-inch diameter by 18-inch wide variable intensity, alternating pole, electrodrum magnetic separator. This separator has a field intensity of about 1200 gauss measured 2 inches from the shell. A water spray directed on the drum face washes away nonmagnetic material. The magnetic concentrate is a dense mixture of small ferrous particles, mill scale and highly magnetic slag. The nonmagnetic product, which contains an appreciable quantity of nonferrous metal values mixed with glass and nonmetals, is ground in a 16-inch diameter by 4-foot long peripheral discharge rodmill. The rodmill discharge is washed and screened on 35-mesh in a 24-inch diameter circular vibrating screen to recover a nonferrous metal oversize product. During grinding, the glass, being triable, is rapidly reduced in size; whereas most of the nonferrous metals, being malleable, are flattened, allowing a screen separation to be easily made.

The minus 35-mesh material is fed to a 26-inch diameter by 1-inch thick rotating disc, matrix-type, magnetic separator. The field strength of the separator in closed gap is 2,500 gauss. In this step the glass is given a final magnetic cleaning, and weakly magnetic particles including some colored glass are separated from nonmagnetic glass.

All minus 20-mesh products from the various screening operations are combined and classified in a 10-inch diameter by 7-foot spiral classifier to remove slime. The slime then is thickened in a 3-foot diameter by 3-foot deep thickener and filtered on an 18-inch diameter by 12-inch vacuum drum filter. Both the sand and slimeproducts contain significant amounts of carbon, alumina, potash and phosphorus.

Materials Balance

Based on data developed in the continuous beneficiation plant, a materials balance for a plant processing 1,000 pounds of dry residues per hour is given in Table 1. The data given should be considered as approximations since residues may not only vary from one incinerator to another but may also vary seasonally as well as geographically.

Operation of the plant when feeding 1,000 pounds of residue solids per hour will yield approximately 166 pounds of large ferrous metal (per hour) composed principally of wire, massive iron and shredded cans. The magnetic material recovered from the minus 4-mesh fraction of the residues, which is composed principally of small iron particles, mill scale, and highly magnetic slag, amounts to about 139 pounds per hour. The total ferrous fraction accounts for about 30.5 percent of the feed. The total production of mixed nonferrous metal concentrate amounts to nearly 28 pounds per hour. During the processing operation, approximately 289 pounds of colorless glass concentrate and 207 pounds of magnetic glass are produced per hour. Both glass fractions account for almost 50 percent of the feed. The minus 20-mesh fraction of the residue, which includes the slime, amounts to only 17.1 percent of the feed.

As shown in Table 2, the quantity of water required for all of the washing operations is approximately 12.9 gallons per minute when processing residues at a feed rate of 1,000 pounds per hour; with proper thickening of slime products, about 97 percent of the wash water used in

TABLE 1
Materials Balance for Continuous Incinerator Residue Processing Plant

Products recovered	*Materials produced* *Pounds per hour*	*Weight percent*	*Cumulative weight percent*
Massive iron and wire	30	3.0	3.0
Plus 4-mesh magnetics	136	13.6	16.6
Plus 4-mesh nonferrous metals	17	1.7	18.3
Minus 4- plus 20-mesh magnetics	139	13.9	32.2
Minus 4- plus 35-mesh nonferrous metals	11	1.1	33.3
Minus 35-mesh nonmagnetic glass	289	28.9	62.2
Minus 35-mesh magnetic glass	207	20.7	82.9
Minus 20-mesh classifier sands	159	15.9	98.8
Thickener slimes	12	1.2	100.0
Composite	1,000	100.0	

the process can be reclaimed. Since the incoming residues contain an appreciable amount of moisture to begin with, more water can be reclaimed than would be used.

TABLE 2
Wash Water Requirements for
Continuous Processing of Incinerator Residues

Washer location	*Water required, gallons per min.*
Trommel	2.6
Primary screen	.7
Secondary screen	2.0
Permanent drum magnet	.5
Secondary shredder screen	.8
Electrodrum and rodmill screen	1.7
Matrix magnetic separator	4.6
Composite	12.9

Evaluation of the Process

The evaluation reported herein was made by the Process Evaluation and Simulation Group at the College Park Metallurgy Research Center using the procedures and techniques described in a Bureau of Mines Report.[6] By extrapolating the data developed in the 1,000-pound per hour continuous processing plant, capital and operating cost estimates were made for a plant designed to treat 250 tons of dry incinerator residues per 8-hour day, 5 days per week. An incinerator discharging 250 tons of dry residue per 24 hours would process about 1,000 tons of raw refuse. The residue would of necessity be stockpiled in storage bins during shutdown of the processing plant. Condensed operating cost estimates for a plant without a fine glass separation section are itemized in Table 3. The estimated operating costs for a plant with a processing section that includes separation of colorless glass from colored glass are given in Table 4.

TABLE 3
Estimated Operating Cost:
250 TPD,[1] No Glass Separation Section

	Annual cost	*Cost per ton residue treated*
Direct cost:		
Materials	$ 1,100	$0.02
Utilities	10,700	.17
Labor	31,200	.48
Maintenance	32,000	.50
Overhead and supplies	19,000	.29
Total	94,000	1.46
Indirect and fixed cost	85,600	1.31
Total operating cost	179,600	2.77

[1] 250 tons per 8-hour day.

TABLE 4
Estimated Operating Cost:
250 TPD,[1] with Glass Separation Section

	Annual cost	*Cost per ton residue treated*
Direct cost:		
Materials	$ 1,100	$0.02
Utilities	16,300	.25
Labor	37,400	.58
Maintenance	40,100	.62
Overhead and Supplies	23,400	.36
Total	118,300	1.83
Indirect and fixed cost	109,700	1.69
Total operating cost	228,000	3.52

[1] 250 tons per 8-hour day.

The estimated operating cost for the plant without a fine glass separation section is $2.77 per ton of dry residue. The estimated capital investment cost for the plant, using mid-1969 prices, is $1,262,000. By incorporating a glass separation section into the processing plant, the estimated operating costs rose to $3.52 per ton of residue, owing to the increase in separation costs and to the cost of drying the material to produce a marketable product. The estimated capital cost for this plant, again on the basis of mid-1969 prices, is $1,627,700.

Refining of Reclaimed Products

The refining of metals and minerals recovered from municipal incinerator residues into products suitable for commerce is also a prime objective of the research. At the Bureau's College Park Metallurgy Research Center, several methods for refining the iron fractions, which contain small amounts of copper and tin, to produce a marketable-grade product suitable as electric furnace feed stock have shown considerable promise. Details on this work will be presented in this paper. Methods also are being developed for separating the complex mixtures of nonferrous metals and refining in individual products. Companies in the aluminum and secondary metals industries and several chemical firms have shown considerable interest in methods for reclaiming and refining this waste metal.

Reclamation of useful glass products has shown considerable promise, too. Fine-sized colorless glass concentrates that would be acceptable as cullet by the glass industry have been produced from incinerator residues by high-intensity magnetic separation. The sorting of glass by colors from relatively coarse, mixed-glass fractions using an electronic optical sorter has been extremely encouraging. Representatives of a number of glass companies and the Glass Containers Manufacturers Institute have shown interest in these phases of the solid waste work and have indicated that markets for reclaimed glass do exist. Research is also being conducted at the Bureau's Tuscaloosa Metallurgy Research Laboratory to determine the feasibility of making such products as bricks and glass wool from fine-sized waste glass recovered from incinerator residues. Consideration is even being given to developing methods for effective utilitization of incinerator residue fines and slimes. Under Bureau of Mines grants, awarded to the University of West Virginia, research to characterize these fractions and to develop methods of recovering and/or utilizing mineral values contained in these materials is currently underway. Research grants also have been awarded to the Universities of Missouri at Rolla, Stanford, Alabama and Wisconsin to seek means of improving the potential utilization of values reclaimed from municipal incinerator residues.

SUMMARY AND FUTURE PLANS

The Bureau of Mines has developed and demonstrated a technically feasible method for processing incinerator residues on a continuous basis to reclaim metal and mineral values. The finalized flowsheet is straight-forward and utilizes conventional mineral engineering equipment. The entire process is comprised simply of a series of shredding, screening, grinding, and magnetic separation procedures. Based on the engineering data developed in the continuous 1,000-pound per hour processing plant, estimates for capital and operating costs for a 250-ton per day plant show encouraging possibilities that the economics may be favorable.

Significant progress also has been made in developing processes for refining the various products reclaimed from incinerator residues. While work in some cases remains to be done to reach the ultimate objective of converting the reclaimed materials into products suitable for recycling, the interest shown by industry has been encouraging.

Research by the Bureau is now being focussed on the development of economical processes for mechanically separating metal and glass from raw urban refuse on a continuous basis. The approach planned is systems oriented because the processes developed must be capable of separating mixtures of a wide range of compositions. Studies to determine the merit of various air classification systems to separate the organic and inorganic fractions of shredded raw refuse are currently in progress. An evaluation of wet separation processes is also underway.

Samples of the inorganic fractions, principally metals and glass, separated by a number of air classification schemes as well as by a pulping technique, have already been characterized. Contact also has been made with personnel of the U.S. Forest Service who have indicated they are extremely interested in recovering cellulose from raw refuse. Without being overly optimistic, it is conceivable that uses can be found for the bulk of materials found in urban refuse, and this so-called solid waste will become a desirable raw material.

REFERENCES

1. Kenahan, C. B., and Sullivan, P. M. "Let's Not Overlook Salvage." *APWA Reporter*, Volume 34, No. 3, March, 1967, p. 5-8.

2. Kenahan, C. B., Sullivan, P. M., Ruppert, J. A., and Spano, E. F. "Composition and Characteristics of Municipal Incinerator Residue." Bureau of Mines Report of Inventory 7204, 1968, 20 pp.

3. Rampacek, Carl. "Reclaiming and Recycling Metals and Minerals found in Municipal Incinerator Residues." IITRI, Mineral Waste Utilization, March 28, 1968, pp. 124-131.

4. Stanczyk, M. H., and Sullivan, P. M. "Physical and Chemical Beneficiation of Metal and Mineral Values Contained in Incinerator Residues." AIME Annual Meeting, February 16-20, 1969. Preprint No. 69-B-54, 12 pp.

5. Kenahan, C. B., Sullivan, P. M., Ruppert, J. A., and Spano, E. F. "Composition and Characteristics of Municipal Incinerator Residues." Bureau of Mines Report of Inventory 7204, 1968, 20 pp.

6. Johnson, Paul W., and Peters, Frank A. "A Computer Program for Calculating Capital and Operating Costs." Bureau of Mines Information Circular 8426, 1969, 110 pp.

Air Classification for Reclamation of Solid Wastes

RICHARD A. BOETTCHER
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Since the enactment of the Solid Waste Disposal Act (PL 89-272) on October 20, 1965, the spotlight of publicity has been thrown on the Nation's solid waste management problem. Under the Act, research and development programs have been initiated to investigate, study and develop new and improved methods of solid waste management.

Those already in the field know that populations whose living habits are undergoing the changes that accompany increased affluence are generating increased quantities of waste; that air pollution legislation that outlaws open burning has brought about rapid increases in the quantities of solid waste; and that massive programs of urban renewal, central city freeway construction, and replacement of older buildings with modern structures have increased demolition wastes.

Also to be considered, along with the quantitative and qualitative changes in the material being collected, are the changes in collection and salvage methods being brought about by continually increasing labor costs. Combined collections have largely replaced segregated collections, thereby reducing collection costs. On-site compaction of commercial wastes containing large quantities of paper and cardboard is a rapidly growing extension of this trend. In only a few specialized cases it is now economical to salvage rags, newspapers, and corrugated cardboard boxes by hand picking such items from combined collections of municipal solid wastes. There is a growing realization of the desirability of reducing the quantity of wastes requiring disposal by reclaiming a portion of the flow for reuse. However, there is also the realization that only processes that are mechanized and that operate continuously can be seriously considered. Acceptable processes require a minimum input of labor per ton of refuse to separate material into those portions that are reusable and those that must be discarded. Air classification is such a process. The purpose of this discussion is to acquaint interested engineers with characteristics of the air classification device and to suggest potential application for separating mixed solid wastes.

SUMMARY

Preliminary research on air classification, as investigated with the zigzag air classification unit developed by Stanford Research Institute, has indicated the feasibility of using this method of separation to process several types of solid waste

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mixtures. Satisfactory separations require:

1. Suitable feed preparation. An air classification unit alone does not usually constitute a complete solid waste processing system. Operations such as shredding, drying, and screening often must be combined with the air classifier to achieve optimum separations. The Bureau of Solid Waste Management has already done some work in this area.[1 2]
2. Particles with maximum dimensions no greater than three-quarters of the least dimension of the column throat.
3. Particles that flow in a granular fashion when fluidized by air. For fibrous materials, this precludes a shredding method that detrimental aerodynamic characteristics and an undesirable agglomeration of the components of the refuse.

The need for feed preparation was revealed by work with all three types of waste processed experimentally — wastepaper; aged, stockpile compost; and nonferrous trash from auto body processing.

With wastepaper, shredding was essential before air classification. Shredding is not practiced at the present time, except to a limited extent in recovery of usable corrugated and high grade mixed papers from commercial and industrial collections. However, shredding is practiced for municipal wastes being composted and for developmental transfer/baling, retorting, incineration, and landfill operations. Thus, it would not represent an additional processing step in these methods of refuse handling.

Compost that has been aged in outdoor stockpiles requires additional light shredding to break up lumps before it can be air classified to remove impurities, even though it has already been shredded in normal processing. Needed feed preparation for air classification of compost also includes drying and screening, because of the presence of large amounts of fine material that behave aerodynamically the same as low bulk density cellulosic components. This is also true for wastepaper.

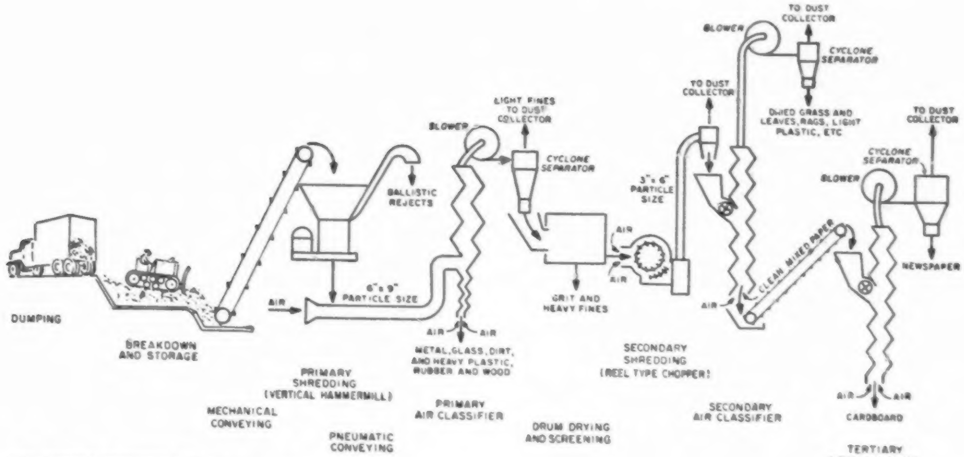
Nonferrous trash from auto body processing could be separated effectively without special feed preparation in an air classifier designed to handle quantities available from typical auto body fragmentizing operation. In certain applications, it probably would be desirable to remove oversize material by screening to reduce the required size and power requirements of the air classification device. In the experiments performed as part of this research, screening of the auto body trash was necessary because of the small throat size of the laboratory column.

It is important to note that limitations observed in the operation of the zigzag classification unit on wastepaper are those related to the size of the unit and the characteristics of methods used to produce an acceptably small particle size, rather than from limitations of air classification itself as a method of separation. Thus, separating usable wastepaper from municipal refuse appears to be technically feasible in an integrated system employing air classification, even though such feasibility was not conclusively demonstrated in these experiments. A conceptual system is shown schematically in Figure 1. The high capacities, low equipment cost, and low power requirements of such a system, as illustrated by calculations for a compost processing operation, should make wastepaper salvage by air classification economically feasible as well. Large markets exist for secondary fiber of acceptable quality. Consequently, a significant contribution can be made to conservation of the Nation's forest resources by increased recycle of air-classified wastepaper.

Laboratory Unit

Zigzag air classification has been pioneered by Stanford Research Institute for processing dry mixtures containing material that can be fluidized and transported in an airstream. Particles of these mixtures are fractionated according to density, size, and aerodynamic properties. Thus, zigzag air classification is somewhat analogous to distillation of hydrocarbon liquids in a petroleum refinery fractionating column. The zigzag principle permits separation of materials with only slightly differing densities whose other properties, such as size, are identical; in almost all cases examined, the zigzag system has proved to be more efficient than any other type of air classification system.

Figure 2 illustrates the laboratory air classification unit used in the Institute's basic experiments to develop process data for the suggested applications. It is a 12-stage, zigzag column (fed at the eighth stage from the bottom), through which air is drawn by a high capacity induction blower. The blower draws air first through the column and then through a conventional cyclone separator that removes material passing upward through the column. Heavy material that cannot be transported in the airstream at any set velocity moves counter-current to the stream and is discharged from the bottom of the column. The separation achieved by the process can be observed through the transparent side walls of the column. The 1-hp induction blower provides superficial velocities


DUMPING
BREAKDOWN AND STORAGE
MECHANICAL CONVEYING
AIR
6" x 9" PARTICLE SIZE
BALLISTIC REJECTS
PRIMARY SHREDDING (VERTICAL HAMMERMILL)
PNEUMATIC CONVEYING
BLOWER
LIGHT FINES TO DUST COLLECTOR
CYCLONE SEPARATOR
AIR
AIR
METAL, GLASS, DIRT, AND HEAVY PLASTIC, RUBBER AND WOOD
PRIMARY AIR CLASSIFIER
GRIT AND HEAVY FINES
DRUM DRYING AND SCREENING
AIR
AIR
3" x 6" PARTICLE SIZE
SECONDARY SHREDDING (REEL TYPE CHOPPER)
TO DUST COLLECTOR
BLOWER
TO DUST COLLECTOR
CYCLONE SEPARATOR
DRIED GRASS AND LEAVES, RAGS, LIGHT PLASTIC, ETC
AIR
CLEAN MIXED PAPER
SECONDARY AIR CLASSIFIER
TO DUST COLLECTOR
CYCLONE SEPARATOR
BLOWER
NEWSPAPER
AIR
AIR
CARDBOARD
TERTIARY AIR CLASSIFIER

NOTE: SECONDARY AND TERTIARY AIR CLASSIFICATION COLUMNS ARE SUFFICIENTLY SIMILAR THAT A SINGLE COLUMN MIGHT BE USED IN A TIME-PHASED OPERATION BY STORING THE CLEAN MIXED PAPER PRODUCT AND RUNNING IN THE SECONDARY COLUMN WHEN NO REFUSE IS BEING RECEIVED

Figure 1: Conceptual Solid Waste Processing System

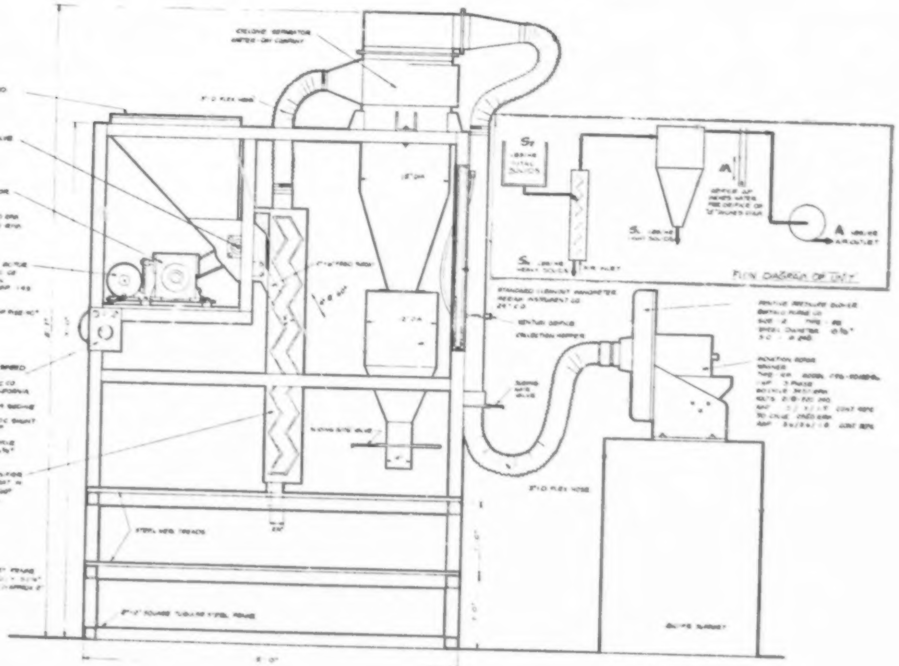

CYCLONE SEPARATOR
TOTAL SOLID FEED
3" I.D. FLEX HOSE
18" DIA
12" DIA
S_T
S_L
S_H
A
AIR INLET
AIR OUTLET
FLOW DIAGRAM OF UNIT
VENTURI ORIFICE
COLLECTION HOPPER
3" I.D. FLEX HOSE

Figure 2: Diagram of the Primary Air Classifier

up to 3000 fpm for fluidizing material in the 2-by 6-inch throat of the classifier.

When operated to separate a mixture of two uniform granular materials of different aerodynamic characteristics, it is a simple matter to adjust the airflow — as the mixture is fed at a uniform rate into the column — so that conditions of feed rate and airflow are achieved that permit free flow of solid material both up and down the column. Under these conditions, heavy and light materials are separated and re-entrained at each of the steps in the column. The falling material and the upward flowing air, which is transporting the lighter material, provide a combined centrifugal and entrainment action, as shown in Figure 3.

A summary of fluidizing velocities, observed when the laboratory column was operated on selected pure components of municipal refuse mixtures, is given in Table 1. These data on shredded, fibrous materials show the effects of the size of a particle and the sharpness of its edges of fluidizing velocity. In comparing fluidizing velocities for paper and cardboard in a 6-inch straight pipe with those in the zigzag column, the straight pipe velocities are approximately one-third lower than those in the column for the same material (dry, shredded newspaper, and corrugated cardboard rounds). Shredded and cut newspaper appeared to differ little in fluidizing velocities in either the column or the straight pipe, and there was no observable difference in straight pipe velocities for large or small cut paper specimens. On the other hand, cut cardboard required a one-fourth to one-third greater velocity than did the shredded material, and large squares required about 50 percent greater velocity for suspension than did small rounds. This is of considerable significance for separation; whereas there exists a 250 fpm velocity difference between cardboard and newspaper (about 50 percent of the lower fluidizing velocity) when finely shredded, a difference of 650 fpm in velocity exists between large pieces (almost 200 percent of the lower fluidizing velocity) when they are cut to minimize the aerodynamic effect of torn edges. The greater air velocities also would permit greater particle agitation for removal of entrapped fine particles.

It was concluded from bench-scale experiments with the laboratory unit that air classifica-

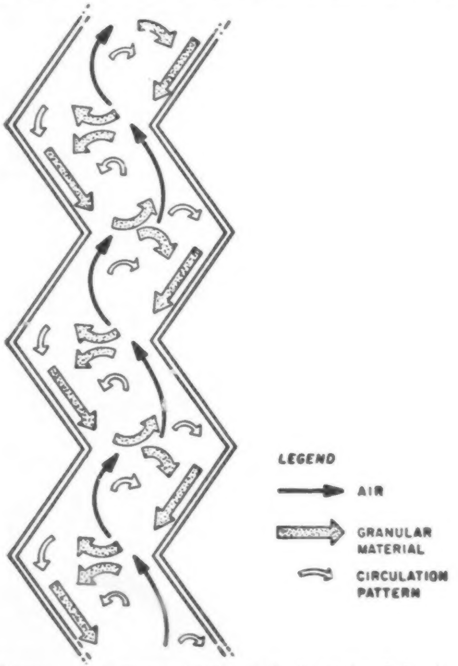


Figure 3: Diagramatic Sketch of the Principle of the Air Classifier

TABLE 1

Component	Velocity (ft/min)	
	2-Inch Throat Zigzag Classifier	Straight 6-Inch-Diameter Pipe
Plastic wrapping (shirt bags)	Less than 400 (electrostatic)	—
Dry, shredded newspaper (25% moisture)	400-500	350
Dry, cut newspaper		
1-inch rounds	500	350
3-inch squares	—	350
Agglomerates of dry, shredded newspaper and cardboard	600	—
Moist, shredded newspaper (35% moisture)	750	—
Dry, shredded corrugated cardboard	700-750	450-500
Dry, cut, corrugated cardboard 1-inch rounds	980	700
3-inch squares	—	1000
Styrofoam packing material	750-1000 (electrostatic)	—
Foam rubber (½-inch squares)	2200	—
Ground glass, metal, and stone fragments (from auto body trash stream)	2500-3000	—
Solid rubber (½-inch squares)	3500	—

tion is technically feasible for processing semifibrous solid waste materials such as compost and auto body trash. For light, more fibrous materials such as municipal refuse, the results were favorable but inconclusive. Additional research is necessary to demonstrate a workable process for paper stock recovery from combined collections of municipal and commercial wastes. This work must include experiments with a larger air classification column and investigations into the performance of commercially available shredding and screening equipment on high paper content feeds. Improvement of commercially available feed preparation equipment (shredders and screens) may be necessary for use in an air classification system.

It is possible from laboratory air classification results to scale up to commercial size equipment. Scale-up factors are listed in Table 2. However, because of the empirical nature of the relationships among the factors that influence air classifier operation, it is necessary to establish experimentally those relationship of importance for any desired separation. This involves: 1) determination that the mixture of materials can be processed satisfactorily, and 2) establishment of the degree of separation that is desirable or possible. When a satisfactory separation has been achieved at small scale, it is then possible to expand the operation to the scale at which commercial processing is contemplated.

In the case of compost, both requirements could be satisfied; the material could be handled in the laboratory unit and, by comparison with other acceptable compost materials (such as dried sewage sludge and dairy manure), performance criteria for the quality requirements of commercial separation could be approximated. Thus, it was possible, on the basis of results obtained in this study, to estimate the performance of a full-scale plant for compost processing.

Processing Compost From Municipal Refuse

Two 14-foot air classifiers were selected for a 30-ton/hr compost plant (Figure 4). The classifier for removing plastic and other light material from the coarse screenings before recycling or bulk sale is an eight-stage unit with a throat size 12 by 82 inches. The column for separating glass and other heavy contaminants from horticultural grade compost is 12-stage and has throat size 8 by 65 inches. Five-horsepower blowers would be required on each column, but the operating power requirement would normally be less than 7.5 hp for both units. The two columns, complete with

TABLE 2

Item	*Ratio or Unit*	*Remarks*
Throat area	Throat of prototype/throat of pilot unit	Column capacity scale-up factor
Column width (throat length)	Width of prototype/width of pilot unit	Variable, to give desired column capacity at necessary fluidizing velocity.
Throat width	Throat of prototype/throat of pilot unit	Variable; widening throat increases column height. Actual prototype throat width determines maximum particle size (oversize) that can be fed.
Column height ratio	Height of prototype/height of pilot unit	Geometrical scale-up: wider throat requires taller column for same number of flow reversals or "plates." Reduced number of effective "plates" reduces separation efficiency.
Flow ratio	Cfm of prototype/cfm of pilot unit	Numerically the same as throat area ratio, since same superficial velocity must be maintained.
Pressure drop	Inches of water	For same throat velocity and loading, column pressure drop of prototype is same as for pilot unit. Add approximately 2-in. water for prototype cyclone.
Power requirement	Horsepower	Calculated from prototype blower cfm and pressure drop. Not determined for pilot unit.

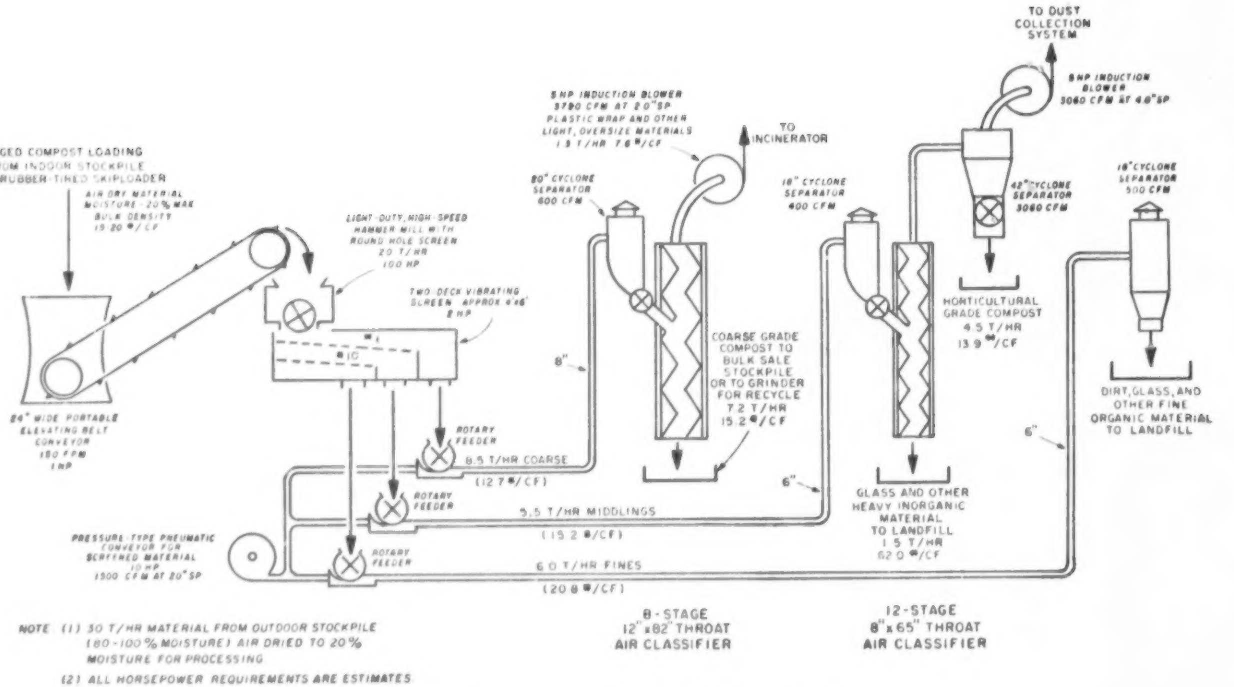

AGED COMPOST LOADING
FROM INDOOR STOCKPILE
BY RUBBER-TIRED SKIPLOADER
AIR DRY MATERIAL
MOISTURE - 20% MAX
BULK DENSITY
15-20 #/CF
24" WIDE PORTABLE
ELEVATING BELT
CONVEYOR
180 FPM
1HP
LIGHT-DUTY, HIGH-SPEED
HAMMER MILL WITH
ROUND HOLE SCREEN
20 T/HR
100 HP
TWO-DECK VIBRATING
SCREEN APPROX 4'x6'
2 HP
#4
#10
ROTARY
FEEDER
8.5 T/HR COARSE
(12.7 #/CF)
ROTARY
FEEDER
5.5 T/HR MIDDLINGS
(15.2 #/CF)
ROTARY
FEEDER
6.0 T/HR FINES
(20.8 #/CF)
PRESSURE-TYPE PNEUMATIC
CONVEYOR FOR
SCREENED MATERIAL
10 HP
1500 CFM AT 20" SP
5 HP INDUCTION BLOWER
3790 CFM AT 2.0" SP
PLASTIC WRAP AND OTHER
LIGHT, OVERSIZE MATERIALS
1.3 T/HR 7.6 #/CF
TO
INCINERATOR
20" CYCLONE
SEPARATOR
600 CFM
8"
COARSE GRADE
COMPOST TO
BULK SALE
STOCKPILE
OR TO GRINDER
FOR RECYCLE
7.2 T/HR
15.2 #/CF
18" CYCLONE
SEPARATOR
400 CFM
6"
TO DUST
COLLECTION
SYSTEM
5 HP INDUCTION
BLOWER
3060 CFM AT 4.0" SP
42" CYCLONE
SEPARATOR
3060 CFM
HORTICULTURAL
GRADE COMPOST
4.5 T/HR
13.9 #/CF
GLASS AND OTHER
HEAVY INORGANIC
MATERIAL
TO LANDFILL
1.5 T/HR
62.0 #/CF
18" CYCLONE
SEPARATOR
500 CFM
6"
DIRT, GLASS, AND
OTHER FINE
ORGANIC MATERIAL
TO LANDFILL
8-STAGE
12"x82" THROAT
AIR CLASSIFIER
12-STAGE
8"x65" THROAT
AIR CLASSIFIER
NOTE (1) 30 T/HR MATERIAL FROM OUTDOOR STOCKPILE
(80-100% MOISTURE) AIR DRIED TO 20%
MOISTURE FOR PROCESSING
(2) ALL HORSEPOWER REQUIREMENTS ARE ESTIMATES

Figure 4: Conceptual Processing System for Upgrading Compost

blowers and cyclones, would cost approximately $42,500. A complete processing plant would also require equipment for shredding and screening, as well as facilities for in-plant materials handling. Such a plant would handle 30-tons/hr of stockpile compost at 80-100 percent moisture content, after it had been air-dried to a maximum moisture content of 20 percent. The actual plant throughput of air-dried compost would be 20 tons/hr. Using the unit's capacity on air-dried material as a base, an estimate of cost suitable for preliminary comparison with other methods of compost processing indicates that the capital investment in such a plant, excluding land, would approximate $5000/ton/hr capacity in this size range. Plant operating cost, including depreciation, is estimated to be 50¢/ton (dry basis) for a single-shift operation and 30¢/ton for three-shift operation. Of the latter figure, approximately 20¢/ton is attributable to the cost of shredding.

Processing Auto Body Waste

In the case of auto body waste, only one of the conditions required for scale-up was satisfied. The waste could be separated satisfactorily in the small laboratory column, but no information was provided on the beneficiated feedstock requirements for subsequent nonferrous metal recovery processing.

Thus, the process for nonferrous metal recovery from auto body trash could not be developed to the extent possible for compost. Air classification runs on auto body material demonstrated only that close separations could be made; there was no attempt to optimize these separations or to concentrate any particular metallic constituent. However, the results achieved were sufficient to permit comparisons to be made of conceptual air classification processing with the process currently being employed for ferrous metal separation and a proposed process for nonferrous recovery. Process diagrams are given in Figures 5, 6, and 7.

A typical auto body shredding operation is illustrated in Figure 5. Because of air pollution reg-

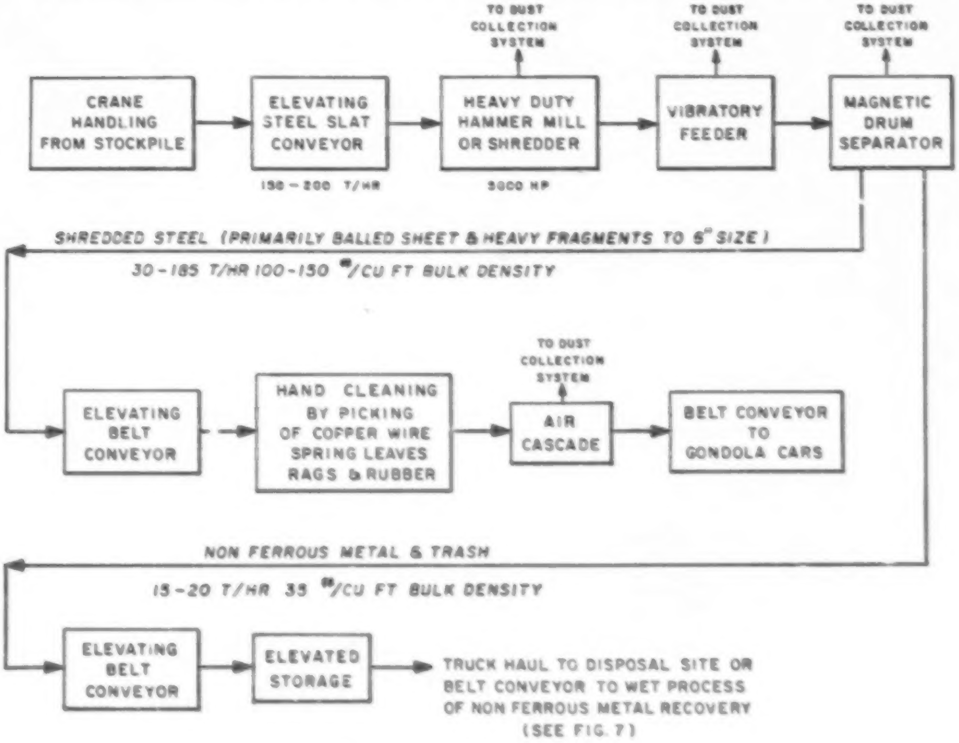

TO DUST COLLECTION SYSTEM
TO DUST COLLECTION SYSTEM
TO DUST COLLECTION SYSTEM
CRANE HANDLING FROM STOCKPILE
ELEVATING STEEL SLAT CONVEYOR
150 – 200 T/HR
HEAVY DUTY HAMMER MILL OR SHREDDER
3000 HP
VIBRATORY FEEDER
MAGNETIC DRUM SEPARATOR
SHREDDED STEEL (PRIMARILY BALLED SHEET & HEAVY FRAGMENTS TO 6" SIZE)
30 - 185 T/HR 100 - 150 #/CU FT BULK DENSITY
ELEVATING BELT CONVEYOR
HAND CLEANING BY PICKING OF COPPER WIRE SPRING LEAVES RAGS & RUBBER
TO DUST COLLECTION SYSTEM
AIR CASCADE
BELT CONVEYOR TO GONDOLA CARS
NON FERROUS METAL & TRASH
15 - 20 T/HR 35 #/CU FT BULK DENSITY
ELEVATING BELT CONVEYOR
ELEVATED STORAGE
TRUCK HAUL TO DISPOSAL SITE OR BELT CONVEYOR TO WET PROCESS OF NON FERROUS METAL RECOVERY (SEE FIG. 7)

Figure 5: Process Flowsheet for Secondary Metals

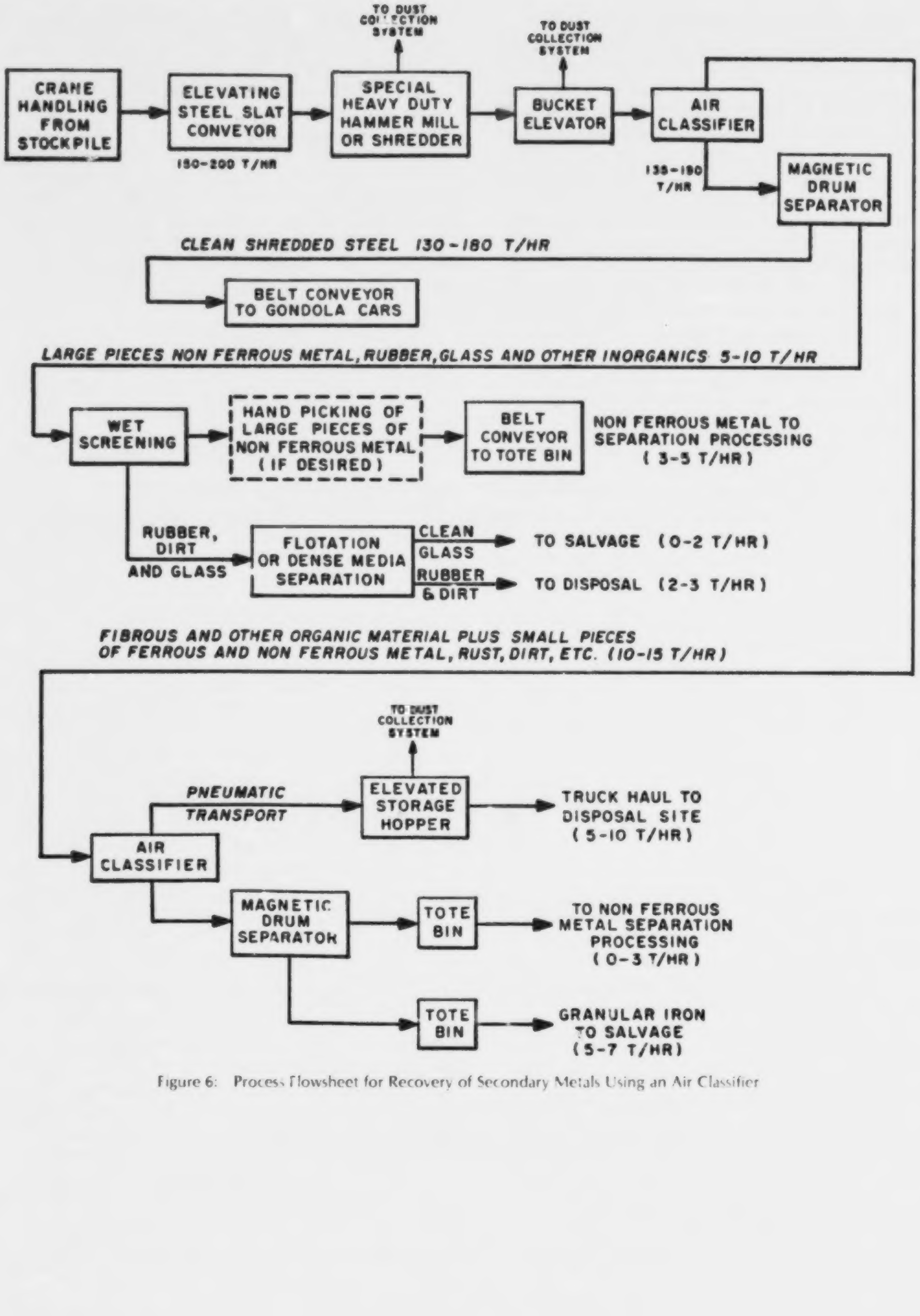

TO DUST COLLECTION SYSTEM
TO DUST COLLECTION SYSTEM
CRANE HANDLING FROM STOCKPILE
ELEVATING STEEL SLAT CONVEYOR
150-200 T/HR
SPECIAL HEAVY DUTY HAMMER MILL OR SHREDDER
BUCKET ELEVATOR
AIR CLASSIFIER
135-190 T/HR
MAGNETIC DRUM SEPARATOR
CLEAN SHREDDED STEEL 130-180 T/HR
BELT CONVEYOR TO GONDOLA CARS
LARGE PIECES NON FERROUS METAL, RUBBER, GLASS AND OTHER INORGANICS 5-10 T/HR
WET SCREENING
HAND PICKING OF LARGE PIECES OF NON FERROUS METAL (IF DESIRED)
BELT CONVEYOR TO TOTE BIN
NON FERROUS METAL TO SEPARATION PROCESSING (3-5 T/HR)
RUBBER, DIRT AND GLASS
FLOTATION OR DENSE MEDIA SEPARATION
CLEAN GLASS
TO SALVAGE (0-2 T/HR)
RUBBER & DIRT
TO DISPOSAL (2-3 T/HR)
FIBROUS AND OTHER ORGANIC MATERIAL PLUS SMALL PIECES OF FERROUS AND NON FERROUS METAL, RUST, DIRT, ETC. (10-15 T/HR)
TO DUST COLLECTION SYSTEM
PNEUMATIC TRANSPORT
ELEVATED STORAGE HOPPER
TRUCK HAUL TO DISPOSAL SITE (5-10 T/HR)
AIR CLASSIFIER
MAGNETIC DRUM SEPARATOR
TOTE BIN
TO NON FERROUS METAL SEPARATION PROCESSING (0-3 T/HR)
TOTE BIN
GRANULAR IRON TO SALVAGE (5-7 T/HR)

Figure 6: Process Flowsheet for Recovery of Secondary Metals Using an Air Classifier

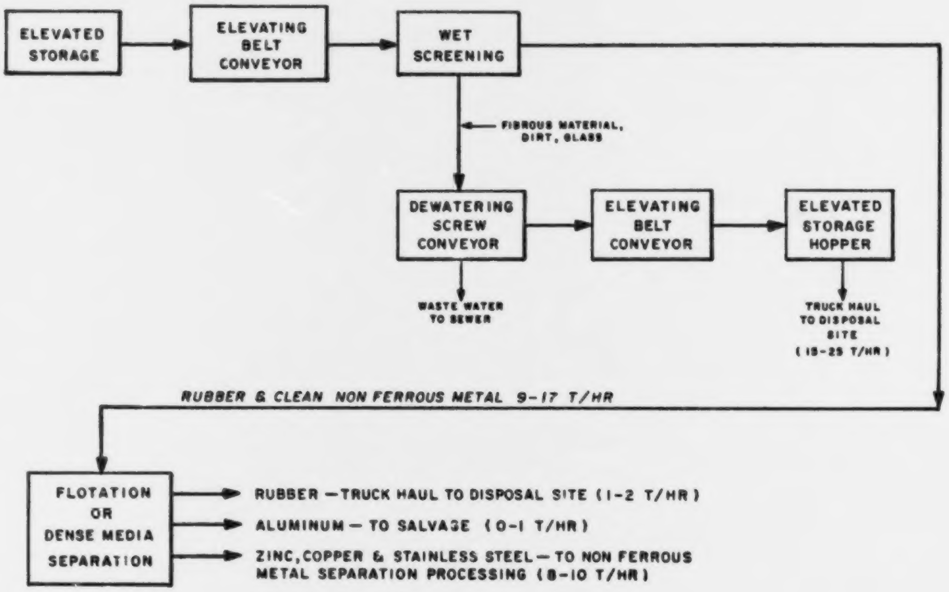
ulations, upholstery and other combustibles cannot be removed by burning before shredding. Consequently, mangetic separation leaves this material in the nonferrous stream. Another consequence of not being able to burn is an explosion hazard, the result of dust from shredding and subsequent material handling operation; this dust must be collected to prevent air pollution, as well as to control the explosion hazard.

Figure 6 shows how air classification could improve the conventional separating process. Magnetic separation is still employed; however, its effectiveness is increased by the prior removal of all fibrous material by air classification, which also eliminates hand picking to remove contaminants such as rags, rubber, and copper wire. Air classification also more effectively removes the dust from the ferrous stream than do the air cascades frequently employed for this purpose.

Further advantages of air classification are evident when the processing system is expanded to include the recovery of nonferrous metals. Figure 7 shows a wet process that is under construction for separating rubber, aluminum, zinc, copper, and stainless steel from the trash stream currently disposed in a landfill. Even though approximately 15 tons/hr of material is recovered, the weight of material requiring disposal is not reduced (and disposal costs remain unchanged) because the fibrous material has become water-soaked in the process. When air classification is employed (Figure 6), the wet-screening and flotation is done on a smaller stream of material, which reduces the required size of new equipment or increases the capacity of an existing installation. The material for landfill disposal is dry, having been removed by air classification rather than wet-screening, and its weight is less by approximately 50 percent.

In summary, advantages of the modified processing system employing air classification are:

1. Improves efficiency of magnetic separations by removal of fibrous material from magnetic separator feed.
2. Eliminates hand picking for final clean-up of steel.
3. Reduces dust content of steel.
4. Reduces cost of dust collection installation.
5. Reduces amount of material requiring landfill disposal.


ELEVATED STORAGE
ELEVATING BELT CONVEYOR
WET SCREENING
FIBROUS MATERIAL, DIRT, GLASS
DEWATERING SCREW CONVEYOR
ELEVATING BELT CONVEYOR
ELEVATED STORAGE HOPPER
WASTE WATER TO SEWER
TRUCK HAUL TO DISPOSAL SITE (15-25 T/HR)
RUBBER & CLEAN NON FERROUS METAL 9-17 T/HR
FLOTATION OR DENSE MEDIA SEPARATION
RUBBER —TRUCK HAUL TO DISPOSAL SITE (1-2 T/HR)
ALUMINUM — TO SALVAGE (0-1 T/HR)
ZINC, COPPER & STAINLESS STEEL — TO NON FERROUS METAL SEPARATION PROCESSING (8-10 T/HR)

NOTE: FOR USE WITH CONVENTIONAL AUTOMOBILE BODY SHREDDING SYSTEM, FIG. 5.

Figure 7: Wet Process for Recovery of Non-Ferrous Metals

6. Permits simple, hand-salvage operation on larger fragments of nonferrous metal, if desired, by separation from fibrous trash.
7. Increases capacity of wet-screening and flotation equipment.

Processing Wastepaper

Because of the size limitations of the laboratory air classification column and the accompanying problems of shredding the refuse to be processed, it was not possible to demonstrate conclusively that the salvage of a usable grade of paper from municipal refuse was technically feasible. Since satisfactory classification could not be effected, the process flow diagram (Figure 1) developed for paper recovery processing is indicative only of the conditions anticipated for a full-size column and larger sized particles with more sharply cut edges (relative to the size of particle) than were obtained in the laboratory shredder. However, it is believed that a new grade of clean and uniformly shredded paper consisting of mixed newspaper, kraft paper stock, and corrugated cardboard—with little or no styrofoam packing, sheet plastic, and only small percentages of paper or paperboard that is highly filled (such as magazine stock) or that contains waterproofing (such as waxed paper, butter cartons, and the like)—could be produced economically on a commercial scale from combined domestic wastes. Such a reclaimed product would have value and might open up a new market for secondary fiber in the paper industry.

Initial studies to establish the feasibility of such reclamation have been authorized by the Bureau of Solid Waste Management. An 8-stage zig-zag column air classification unit has been built that has a throat size of 6-inches by 12-inches. The particle size of shredded paper that can be processed in this larger column is representative of the output of commercial shredders. However, it has been found that characteristics of the shredded refuse have a great influence on air separation efficiency. Shredders or pulverizers such as those used in Europe[3] for pretreatment of refuse to be composted or used as landfill with a minimum of earth cover are often unsatisfactory. This is particularly true of the drum-type pulverizers that are operated with water. Shredder output characteristics now being specified for reclamation processing of municipal solid waste by air classification include the following requirements:

Paper and Corrugated Board

Particles to be individually separable, to have 4-inch to 5-inch maximum dimension, and to be roughly rectangular with a ratio of length to width of no more than 2:1. Cleanly cut edges are preferable to torn edges; frayed, mechanically worked edges are unacceptable.

Glass

Size gradation of particles to have a maximum quantity in the 1/4-inch to 3/4-inch range.

Metal

Cans to be reduced to crumpled balls or shreds of less than 2-inch maximum dimension. Miscellaneous metal not to exceed 3-inch maximum dimension. No single piece of shredding equipment has been found to date that can simultaneously meet all of these output requirements.

The recycling of wastes can have important effects on waste management costs. In the United States, paper currently accounts for about 5 percent, by weight, of municipal solid wastes. Secondary fiber (wastepaper) represents the second largest supply of fibrous raw material, following wood pulp, for the U.S. paper industry. Between 10 percent and 20 percent of this paper is now salvaged and reused according to one source.[4]

Assuming that there is a market for recycled paper, this same source estimates waste management costs for each level of recycling. In New York City, for instance, where paper not recycled is disposed of along with other solid wastes by incineration, subsequent disposal of the incinerator residue being by sanitary landfill, it is estimated that the annual disposal cost for 20 percent recycle is about one and one-half times the cost for 80 percent recycle, a difference of approximately $100 million annually for the New York region.

Another source[5] estimates that, in 1966, 10 million tons of paper stock (wastepaper) were recycled and became raw material for new products. The U.S. Forest Service predicts the volume will reach 17 million tons by the year 2000. Employment in 1958 to collect this material and get it to market involved 10,000 employees with a payroll of $45 million. Wastepaper provides about 25 percent of the raw material for the paper and paperboard industries. The total value of paper stock (wastepaper to consuming mills) is greater than $300 million per year. A beneficial effect on conservation was the fact that 12,800,000 cords (13 million acres) of trees did not have to be cut in 1966 because of the 10 million tons of wastepaper that were used in place of wood (that is, raw material).

Comparative paper reuse in the United States and foreign countries for which data are available is estimated to be:

1. United States, 10 percent (minimum estimate) and 25 percent (maximum estimate).
2. United Kingdom, 27 percent.

3. West Germany, 33 percent.
4. Japan, 46 percent.

New markets are probably essential for a new recycled paper product because of the quantities involved. The city of Los Angeles, excluding the smaller cities of the metropolitan area and commercial collectors in the unincorporated areas of Los Angeles County, picks up approximately 5,000 tons of domestic waste daily. During the 1970's a number of municipal transfer stations will become justified on the basis of transportation economics alone; the minimum size of a transfer station will be 300 tons/day. Los Angeles basin cities, such as Santa Monica and Beverly Hills, have been operating refuse transfer stations for a number of years. In Orange County, two transfer stations have operated since 1964, and each now processes over 500 tons/day. A third transfer station recently has been completed. Future expansion of these stations to a capacity of 800-1000 tons/day is possible. Thus, considering only facilities already in operation or contemplated in the greater Los Angeles area, a minimum of 3000 tons/day of refuse will probably be handled through municipally built transfer facilities by 1975. If salvage contractors were to operate these stations under no-cost contracts and process the refuse to recover only 25 percent of the incoming material as mixed paper, an assured supply of 750 tons/day would result. At a price of only $5 per ton, the dollar value of the recovered paper would be over $1 million per year. In addition, Los Angeles and Orange counties and their municipalities would save the present cost of transfer station operation, haul costs would be reduced by 25 percent, and landfill life would be extended.

Related Applications

The ease with which noncombustible material can be removed from municipal refuse has been demonstrated in the laboratory. Air classification is being incorporated in the process flow diagrams of the 400 tons/day combustion power unit (CPU-400) now under development. This unit will produce electrical power in a gas turbogenerator from solid waste that has been gasified by combustion or pyrolysis in high pressure, fluidized-bed retorts.

When refuse is already shredded, as for composting or fluidized-bed combustion, glass, dirt, rubber, metallics, and wood and heavy plastics (which typically represent 20-25 percent by weight of municipal refuse) can be removed for less than 10¢ per ton by air classification. This opens up many possibilities for recovering usable materials such as ferrous metal and glass. It is known that secondary materials processors are keenly aware of, and are interested in, all developments related to new salvage opportunities. The Sanitary Engineering Research Laboratory of the University of California at Berkeley is interested in salvage as a facet of solid wastes management.[6]

One further application that appears to merit investigation by those researchers working with refuse incineration is the removal of heavy materials from the incinerator feed by shredding and air classification. Besides the salvage possibilities that would be created, incinerator operation and maintenance costs might be reduced by such removal. New methods of combustion, such as fluidized-bed and grateless systems employing injection of shredded material by blowers or ram-type packers, become worthy of consideration. In conventional incineration, the recovery of materials from the ashed residue by air classification, while not yet investigated by the Institute or others, appears to offer some promise for economical recovery and reuse of secondary materials.

CONCLUSIONS

Separation of heavy materials from dry, shredded, municipal, and commercial refuse can be accomplished easily. It is possible to insert an air classification column into a vertical run of pneumatic conveyor piping handling the output of a refuse shredder and to remove metal, glass, rocks, rubber, and wood from the shredded refuse. The cost is estimated to be less than 10¢ per ton, including the cost of pneumatic conveying. Such a separation should be highly desirable in refuse composting, refuse retorting, and for certain experimental types of refuse incineration. It has been adopted as part of the flow diagram of the CPU-400 (combustion power unit) system of refuse gasification.

Conceptually, air classification can provide a number of benefits in the processing of shredded auto body material, including: 1) improved cleanliness and reduced nonferrous contamination of the steel scrap; 2) reduced quantities (and cost) of waste requiring landfill disposal; and 3) increased capacity of nonferrous recovery processing facilities.

Compost can be cleaned of glass and other contaminants that reduce its marketability. Yields of over 50 percent combined bulk and horticultural grade material can be produced by an air classification process developed by laboratory column operation. In a 30-ton/hr plant, the cost is estimated to be 30¢ per ton of material processed (24-hr operation), including amortization.

Other findings of importance include the following:

1. The laboratory air classifier is a useful tool for empirical design.

2. For a particular type of refuse and a particular reclamation objective, final system design requires that separations be optimized by a more extensive series of experiments than was performed herein.

3. Empirical determination of design criteria for full-scale air classification systems, especially for wastepaper, requires an experimental column larger than the laboratory unit used for the reported experiments.

4. The characteristics of material shredded by commercially available shredders must be determined as part of the experimental work on any particular type of refuse requiring shredding.

5. Commercial interest might be stimulated by the construction of a demonstration plant for salvage of paper or other secondary raw materials from refuse.

6. Nonferrous metal recovery from auto body trash is particularly attractive commercially.

7. Recovery and reuse of glass could stimulate a greater use of nonreturnable glass bottles by the beverage industry.

As a unit operation, the advantage of air classification include:

1. Dry processing capability
2. Sharp, clean separation capability
3. High capacity throughput
4. Low power requirement
5. Low operating manpower requirement
6. Dust-free operation

Air classification is subject to certain limitations, the most significant of which are:

1. Feeder and column throat size impost particle size limitations for low capacity systems

2. Multiple-column or repetitive operation is required for more than two-component separations

3. Oversize, semifibrous materials require shredding before classification.

REFERENCES

1. Engdahl, R. B. Solid Waste Processing: A State-of-the-Art Report on Unit Operations and Processes. Public Health Service Publication No. 1856. Washington, D. C. U.S. Government Printing Office, 1969.

2. Drobny, N. L., Hull, E., and Testin, R. F. Recovery and Utilization of Municipal Solid Waste: A Summary of Available Cost and Performance Characteristics of Unit Processes and Systems. Public Health Service Publication No. 1908. Washington D. C. Government Printing Office, 1969.

3. Patrick, P. K. Waste Volume Reduction by Pulverisation, Crushing, and Shearing. The Institute of Public Cleansing. 69th Annual Conference. Blackpool, England. June 5-9, 1967.

4. New York Regional Plan Association, Waste Management Bulletin No. 107, prepared with the assistance of Resources for the Future, Inc., and the Franklin Institute.

5. University of California. Sanitary Engineering Research Laboratory. Comprehensive Studies of Solid Wastes Management: Abstracts and Excerpts from the Literature, SERL Report No. 68-3, Berkeley, California. June, 1968, p. 236.

6. University of California. Sanitary Engineering Research Laboratory. Comprehensive Studies of Solid Wastes Management, prepared by C. G. Colueke and P. H. McGauhey, SERL Report No. 67-7. Berkeley, California, May, 1967, p. 105-117.

Segregation Systems for Processing Heterogeneous Solid Waste Materials for Resource Recovery

VICTOR BROWN
Metropolitan Waste Conversion Corporation

The beginning of our work in Florida dealing with municipal solid waste was basically intended to convert the large bulk of the material into an organic compost which would be useful for agricultural purposes. Metropolitan Waste Conversion Corporation developed a mechanical digestor system which lent itself to the high production needs of converting the big bulk inputs which come out of the city collections. The first couple of years of effort were spent in the construction, testing and the evaluation of the composting system which proved to be fully as effective and as capable of dealing with the municipal waste as had been anticipated. The system could be sized to handle 10 to 1,000 tons per day.

In the course of working with municipal waste, it became obvious that content of the household and commercial discard had already started to change considerably, which became starkly demonstrated when a number of test evaluations as to the content of the intake to the pilot plant showed only 8 or 9 percent of the material received constituted food waste. Essentially, this is the only "garbage" portion of the municipal delivery and all the rest of it could be termed as trash. A further analysis indicated that on an average, paper ran a big 65 percent of the total, ferrous metal in all forms at 7 percent, nonferrous metal principally as aluminum between .1 and .2 percent, glass at an astounding 8 percent, plastic of all kinds at 3 percent, textiles 1 percent, which left a balance at 16 percent. It came out with impact that in order to make a good quality compost, a great deal of these conglomerate items had to be removed. This is obviously true of the non-organic content. Even in the case of the paper, the volume was too great to be very helpful in the compost business.

In considering the means of dealing with the separation of materials of the nature being discussed, the simplest form of separation is to make a spread of the material and then manually select the items which are to be extracted. Instead of putting things on as the program is conveyed past the individuals, items are removed and deposited in a receptacle for later shipment. This is at once a separation and a classification operation. In the initial approach, this was done in the case of certain glassware and paper and board. The glass business proved to be uneconomical, and so this assortment of bottles and jars was permitted to go on into the compost digester and, with other matter, became part of the contaminant content of that product. Ferrous metal received attention early in the picture, and it was quite easy to set up automatic extraction of this material with a magnetic separator. Experience teaches one that in mechanical separation, it is not so much whether or not the items can be got out, but rather the big question is how much of the materials that are not wanted are mixed in with the items being extracted. In other words, as ferrous metal constituting primarily cans was extracted by this system, the drag-out especially of shredded paper was enormous; and so consequently, secondary clean-up of the product had to be devised — small versus big. In the meantime, instead of referring to the early stages of experience of this work on production extraction of industrial commodities, the paper situation developed an economic tone of its own which spelled out some of the cold facts. Labor dollars to extract and to bale commercial waste paper from municipal solid waste was not a lucrative business. Furthermore, only a very small percentage of the available fibre could be extracted because of the uneconomics of size of the individual pieces; it cost too much to pick out small pieces. Only with the selected input of high paper content type of waste can manual extraction be made to pay off. In processing solid waste with a high degree of heterogeneity, extraction must be dealt with on a mechanical basis not only where the cost of the actual operation is low, but also where the percentage of fibre extraction represents a high proportion of the available fibre. Beginning at these early stages, the program has evolved through a number of development steps including a recent refinement of the system of total mechanical separation at Houston, Texas. It is now a positive established fact that the concept of mechanically separating out these major items of industrial importance, such as metal, glass and paper is both practical and feasible. This does not deny that a great deal of work remains to be done for additional refinement since it is obvious and evident that as new objectives are reached, new horizons will arise. It is now necessary to reach for higher standards of quality, greater efficiency of operation, and most important, the few markets which are established must not become increased to many markets and a host of customers.

A number of methods and various modifications have been used with varying degrees of success in the techniques employed in separating out useful commodities. The discard conglomerate comes in all kinds of shapes and conditions: small items, large items, soft stuff, hard stuff, a lot of loose or individual items, much of it in boxes or bags, some wet, some dry, etc. Therefore, it is required to first chop it up or shred it to a general predetermined size standard. A choice of equipment is available to receive, store, feed and shred it, and the total design concept is predicated on volume to be handled and the production capacity desired. Depending on experience and the layout of the system, it is necessary to consider the sequence of extraction for the various types of material. It appears logical to go after the big bulky items such as the paper first, and then to work on the rest of the material in whatever order is desired. The shredded aggragate is screened in order to separate out fines of all types. Then the rejects are conveyed to a pair of specially designed classifiers which are rated at 25 tons per hour of gross weight of input material. The classifiers using air in proper balance of velocity and volume air lifts the paper, and this is conveyed in a pneumatic conveyor system through a series of driers and cleaners before going to the automatic baler. The refinement of the cleaning stages is the key to making this program really successful; and so consequently, this work is receiving full concentration of effort, and the fulfillment of the objective standards is quite firmly in sight. The last stage in the paper processing involves a drying operation before going to the baler. A high rate baling station composed of two horizontal hydraulic balers, with continuous roller conveyors, feed the carloading dock. This provides a potential capacity for this setup of twenty 1600# bales per hour with each one of the baling machines. Since the plan, as a whole, is a completely integrated operation, each one of the commodities being extracted is a byproduct coming out of the line and must proceed smoothly and efficiently so as not to interfere with the overall production. It was not very long ago when one could consider cans as being part of the ferrous metal mix. Today there are two kinds of cans: one ferrous and another one aluminum. A magnetic separation system can extract ferrous metal of all kinds quite efficiently and continuously. It is necessary to clean out the nonmetal material which is dragged out, but this can be done by double handling through a second magnetic separator or with the use of vibration and/or air. Depending on how the ferrous metal is to be sold, it may not be necessary to separate out the cans from the rest of the scrap metal for sale purposes. This is a matter of market demand and establishing a device for satisfying the customer requirements. In the case of the aluminum, so far the only effective method of extraction is the manual one; therefore, it is essential that this be left to one of the last operations in the line so that the amount of total material confronting the picking station is minimum. If it is desired and markets are available, textiles can be taken out either by a mechanical rag picker or the old manual method. The market is not particularly attractive for this commodity currently, so the best place to put this stuff is with a residue of non-compostable, non-salvageable material for landfill.

Glass is a new item for industrial salvage consideration. In a continuous processing plant such as is being described, there are several spots where the material can be passed over gravity tables which extract a clean glass fraction of mixed color. Having gone through a large shredder or hammer mill, the glass particles are relatively small, averaging probably between 1/8 and 1/4 inch in size. It cannot be certain yet as to the degree of cleanliness necessary. When this is determined, then the amount of subsequent stages for further handling can be prescribed and inserted into the line. The economics of a total system of this nature is determinable to a fairly close extent at the present time. It is obvious that until the markets are fully developed and stabilized, there is sufficient risk in the construction and development of the type of plant to make it necessary to build in a great deal of flexibility and safety into the structure. It is likewise apparent that there is a great potential in the possibility of extracting a great portion of the otherwise lost assets of metals, minerals and fibres, not to mention the conversion of the organic content good for our agricultural community. It is possible to plan for integrating solid waste disposal with basic material produced.

The feasibility of an integration of a municipal waste disposal plant and a paper production mill is not only feasible but very interesting. The high density population center with its heavy accumulation of solid waste, most of which is paper and fibre material, can be the supply of the basic materials for such a paper mill. It can be separated and cleaned in the dry state, and then pneumatically delivered to the hydro pulper in the adjacent paper mill for repulping, wet cleaning and manufactured into finished paper. Here is an absolutely reliable source of input material which cannot be stopped under any conceivable conditions. It is a steady available stream with built-in price stability. Add to these advantages another big advantage of covering freight costs. Under such a circumstance, the handling and the freight involved are absolutely minimal. The proximity of this vast volume of raw materials to the user market naturally provides the lowest element of these costs, a saving which, in turn, will reflect heavily in the overall profitability of such a product. The high density population centers are at once the primary suppliers of reused fibre and are also, in general, the areas of the use customer for the new product.

The real secret to the program of recycling and reuse is not now confined to the establishing of mechanical feasibility but to the opening up of volume markets for accommodating the great potential volumes of new supply. This is a key factor in the total program and must be given much greater emphasis in the future.

Participation is necessary between all elements of solid waste management and private business. In order to capitalize on ingenious new techniques, basic industry must become the willing recipient of a great volume of brand new supplies of raw material backed up by the necessary dealers and brokers who can expediently channel the flow of these goods back into industrial production over the entire world. Cooperation with aggressive purpose between all the elements that come into play must tackle and resolve the big problem of solid waste management by changing it from a national liability into an asset and industrial benefit to the credit of our industries and to our nation.

Storage, Handling, and Disposition of High Melting Organic Residues

C. L. ROY
Merichem Company

Before beginning to discuss this subject, the storage, handling and disposition of high melting organic residues, I think it is important that we first examine why it is necessary to store, handle and dispose of this particular high melting organic residue. In order to understand this, allow me to discuss for a moment the background of the process which produces these residues.

The story begins in the Petroleum Refining industry. There in the early days of refining the refiner discovered that he could sweeten his gasoline and remove the unpleasant odor by washing it with caustic. Caustic washing removed the mercaptans that cause this odor in gasoline and in the case where he had either catalytically or thermally cracked the feed stock to make gasoline, the caustic also reacted with another group of acidic compounds known collectively as cresylic acid. Broken down into their more familiar chemical terms, you may recognize some of the cresylic acids by the name of phenols, cresols and xylenols. In addition to these three general classes of compounds, there are other higher alkylated phenols.

But, back to our refiner for a moment. Before I digressed, I was discussing the fact that he used caustic to remove sulfur compounds, and incidental to that it reacted with cresylic acids. From the very fact that the caustic has reacted with these sulfur compounds and cresylic acids, it is obvious that sooner or later enough of the caustic is used so that it is no longer effective at removing sulfur compounds.

In the early days of refining, the refiner simply dumped this spent caustic into the nearest stream. It did not take long however for this to become an unacceptable practice. It was at this point that the need for the Merichem Company arose.

Merichem accepts the spent caustic from these refineries as a raw material for its process which recovers the valuable cresylic acids. In all, Merichem receives spent caustic from approximately 100 refineries throughout the country.

Now that we have our raw material source defined, let us take a short look at the Merichem process itself. This process consists of removing the unwanted sulfur compounds and neutralizing the caustic with some suitable acid and recovering the cresylic acids that separate out when the caustic is neutralized.

Incidentally, the aqueous layer from the neutralized solution contains sodium sulfide and is marketed to paper mills primarily where it is gaining wide acceptance as a replacement for, or supplement to, salt cake. The organic layer containing cresylic acids, however, is further treated to remove water, sulfur compounds and a mixture of high melting, high boiling organic residues that entered as part of the raw materials. Thus the need to store, handle and dispose of this residue becomes apparent and in reality is a necessity to the process.

As an indication as to how many processes are developed, in the early days the high melting residue from the Merichem process were simply collected in an open pit and set on fire. It did not take long however for the dense smoke that resulted to make apparent that a more desirable disposal process should be found. A series of experiments began somewhat on a crude scale, in which various nozzles were tried with the aim of finding one which would allow the residue to burn with less smoke. Eventually, a nozzle was found that would allow the residue to be burned completely and we will discuss this nozzle at a later point in this talk.

The word that has been coined within our plant to describe these residues is pitch. Now that a method of burning the pitch had been found, it was necessary to design a handling and storage system. The following data were useful in the design:

1) The pitch melting point — 120°C (approximately 250°F) Below this temperature it grows viscose rapidly and below 150°F it hardens to a brittle cold-like solid.

2) This composition is never constant and does vary according to operating conditions in the plant, and the nature of the residue is in the raw material.

3) The specific gravity of the material is approximately 1.15 at 350°F.

4) The heating value of the material is approximately 16,000 BTU's per pound.

5) Upon complete combustion, the ash represents 5% of the charge. This ash contains a great deal of sodium.

6) Once the material is set up as a solid, it is very hard to remelt and apparently tends to self-insulate. Particularly for this latter reason, the conclusion was made that the pitch handling system would have to keep the residue molten, keep it moving and when unable to do this, flush the lines out completely.

The lines for transporting the pitch were sized based on the expected flow rates the maximum being approximately two gallons a minute. The pitch lines are all jacketed with one size larger pipe (let me explain this a little more fully).

Let's assume that the pitch line size is 1" — in this case another line, 1½" is used to enclose the pitch line. This is, of course, a concentric arrangement. In operation, the annular area between the pitch line and the outside line is kept under pressure with 250 lb. steam.

The 250 lb. steam has a condensation temperature of 406°F and from this it is apparent that the temperature of the material in the pitch line itself is kept at 350-400°F. At no point in the line are any dead places allowed. Whenever it is necessary to shut a line down, the line is purged free of residue, using 250 lb. steam.

I have a number of slides here which show this piping arrangement much better than I can describe it verbally. So, let's put the pictures on the screen please.

Figure 1 is a general view of the entry of the Merichem plant and serves as an introduction to the rest of the material you are about to see.

Figure 2 is a picture of a crude acid and finished acid distillation system in the plant. This picture was taken a few years ago and there are additional columns now, but if I might, I would like to direct your attention to the second and third tower from your right as you view the slide. For those of you who have eagle eyes, you can see between these two towers there is another tower that extends approximately one-third of the distance up the second and third tower as you view. For those of you that are sharp-eyed enough to locate this, congratulations. My reasons for directing your attention to this tower is that it is the source for the organic residue which we have been discussing. Figure 3 shows the bottom of this tower. The pipe coming down to the three-way valve is the line that feeds the residue from the tower to the pump. This tower is under approximately 27" mercury. The valve in the foreground is a manual three-way valve and is used to divert the residue to either of two Moyno pumps. These pumps have tool steel rotors and

Figure 1

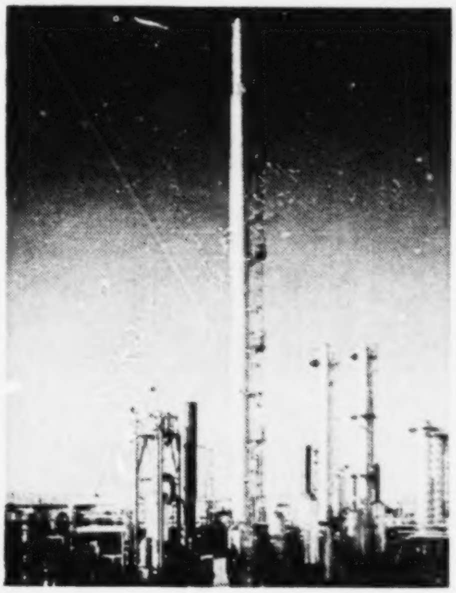


Figure 2

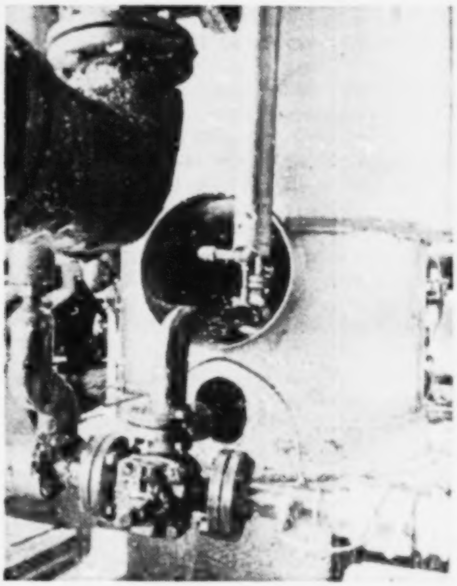


Figure 3

staters and as you will note the pump on your left is steam traced. This is also true of the other. These pumps pump the residue from the bottom of the tower to the storage tank. If, during operations, the tower shuts down there is a steam-out arrangement which allows the residue to be flushed out of the line into the storage tank.

The storage tank itself is 12 feet in diameter by 30 feet tall. The bottom four feet of the tank is heated by a coil constructed of two inch schedule 40 pipe, 250 lb. steam is used as a heating medium and is maintained within the two inch pipe. The temperature on the tank is maintained at 350°F. minimum.

Figure 4 shows the piping as it comes out of the bottom tank. The storage tank is not seen but is off the lower right hand corner of the picture. Residue comes from the tank and flows either to your upper right or the lower left to pumps which feed the residue to the incinerator. The fourth pipe entering this valve is a steam out arrangement and is used whenever the residue is switched from one pump to the other. When this occurs the steam automatically steams out that section of the pipe between the 4 way valve and the pump that has been taken out of use. This steam-out line is the one that has the pressure gauge over it just below the gentleman's chin in the picture. From the storage tank and pump,

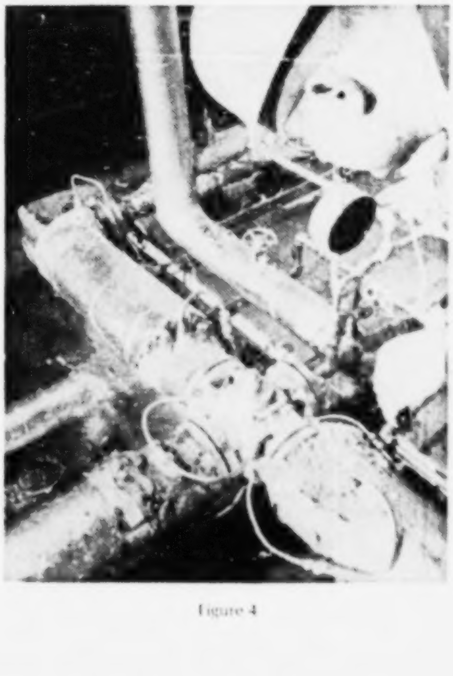


Figure 4

the residue is transported to the incinerator. At the incinerator there is an automatic four-way valve.

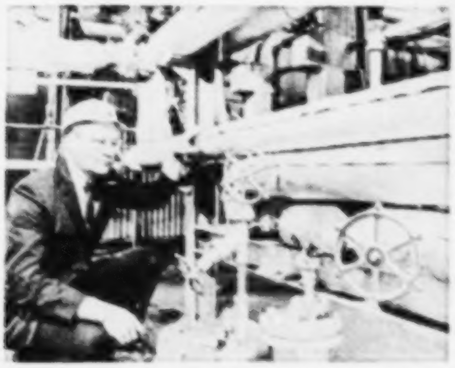
Figure 5: this valve is directly over the kneeling gentleman's head. Pitch from the storage tank is either coming through this valve to the incinerator, or through this valve and to a return line back to the storage tank. If, for any reason the position of the four-way valve is switched, steam enters the four-way valve and flushes the residue out of the unused line. This occurs also when pitch is shut out of the incinerator for any reason. Automatically, steam enters and flushes the line from the 4" valve to the incinerator.

As you have noted, the unique part of this piping system is that there are no dead spots in the line and by use of the four-way valves unused portions of lines are automatically flushed clean with hot steam.

Figure 6 is a view of the incinerator itself. The first view is a distant view and shows the stack. Figure 7 shows the incinerator. You will note that the incinerator is in effect both an incinerator and a boiler in that the hot combustion gases are passed through a heat recovery section. You will note the steam drum that runs the length of the incinerator and is shown at the top. The right hand side of the picture is the burner assembly and the duct work brings outside combustion air, or another air stream which we will discuss in a moment, into the combustion chamber. On top of the incinerator you will note an induced draft fan.

A better feel for what is really going on around the incinerator can be drawn from Figure 8. This figure shows a schematic diagram of the incinerator system. The lower section of this figure shows the four-way valve in the pitch handling system that we discussed. There, you can see that the pitch supply comes in and then goes out one side of the valve while purge steam goes through the valve in the opposite direction back to the storage tank. This figure also gives you the clue that more than one fuel is being incinerated.

In Figure 9 is a line called process air. This is an air stream from our plant that can contain some odoriferous materials and consists of about 5000 actual cubic feet/minute of air at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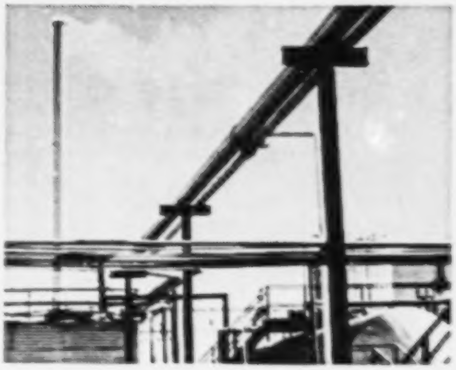
Figure 6

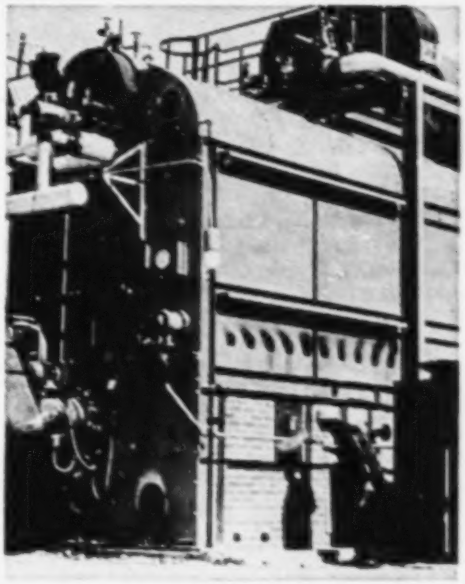
Figure 7

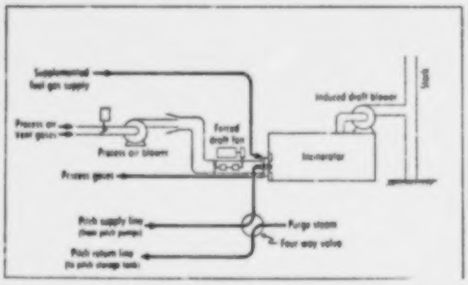

Figure 8: Schematic Diagram of Incinerator System

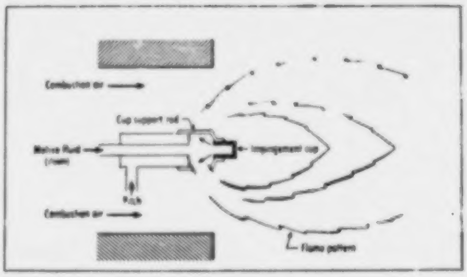

Figure 9: Pitch Nozzle Geometry

120°F. and it is saturated with water vapor. In addition to this air, there are vent gases and process gases coming off of the vent system in the plant being burned in the incinerator, and, of course, there is a supplemental fuel gas supply, methane. Thus I assume it is apparent that this particular incinerator is not used solely to dispose of these high melting organic residues, but also disposes of odoriferous material from the rest of the process, and helps prevent some of the odor problems that could occur in a plant handling mercaptans and other sulfur compounds.

From the number of fuels being burned, one would guess that a fairly sophisticated control system is used for the incinerator. In this case, one's guess would be correct. A series of interlocking circuits make sure that the incinerator is operating properly from the standpoint of draft, water supply and has a proven flame and in the case of the pitch, is in a full fire position before many of the fuels can be admitted to the incinerator. The process air stream going into the incinerator is sometimes subject to varying hydrocarbon content. For this reason, it is monitored continually for explosivity, and when the hydrocarbon concentration reaches a pre-determined level, the process air is automatically shut out of the incinerator for safety reasons until the operations people can correct the problem and re-admit the process air into the incinerator. The incinerator and the control system around it, are in reality a complete subject within itself, and to go into all of the aspects of the controls involved in the incinerator would occupy as much time as I have already taken, so rather than getting deeper in this subject I would like to show you my last slide which gives you some idea of how the residues are broken into a fine enough spray so that the complete incineration can be accomplished.

This slide shows the pitch nozzle geometry. You will note that the motive fluid enters through the throat of the nozzle and the hot pitch is sprayed into the moving steam. The combined steam jets from the nozzle at near sonic velocity and subjects the particles to very large turbulent sheer forces that effectively atomize the pitch. The configuration of the nozzle prevents the base of the flame from playing back to the pitch orifices. Coke and clinkers which cause erratic flow and plugging are eliminated.

The flame temperature incidentally is 2500 to 2800 degrees F.

The incinerator has been in operation for approximately two years. It is unique in that it has served our company as a means of disposing of its high melting residues and as well as waste vent streams and other gases from our plant. The combination of engineering problems that were solved in getting this system of collecting these wastes, transporting them, storing them and incinerating them represents a great deal of professional time for our company.

In summary I would like to remind you that the company, Merichem, has among its business objectives, the abatement of pollution from petroleum refineries, therefore the management feels the company's own operations must be exemplary in pollution control.

For these reasons, the problems I have briefly discussed here were attacked with a great deal of vigor and we are proud of the successful solution.

I have hit the subject matter very lightly, and I hope that I have stimulated questions. Perhaps we can pursue the things you consider interesting by answering some of these questions at this time.

Storage and Handling Systems for Industrial and Commercial Wastes

HARVEY W. LIBERMAN
Dempster Brothers Inc.

Have you ever noticed a large apartment complex with sufficient space for only small 30 gallon garbage cans, in spite of the fact that hundreds of residents may occupy the buildings? Have you noticed a wholesale or retail establishment where there is no space for unpacking the incoming merchandise; or a restaurant with no place for bulk storage of waste food or other refuse from the kitchen, other than G.I. cans outside the kitchen itself?

Possibly, you have noticed receiving departments in factories and warehouses where there is no adequate area for handling waste? In the area of the production process itself, have you noticed that in a number of departments there is a manufacturing process which, as a part of the operation, produces some amount of waste or excess packaging, and yet there is no adequate space left for the waste?

These examples all illustrate the fact that too often people do not consider refuse handling as a part of the overall systems operation: whether it be an apartment house, an industrial manufacturing plant, or commercial distribution center. Waste storage and handling systems should be considered when planning these facilities. This planning should not be done as an afterthought.

There is no panacea in using terms like laser evaporation, atomic destruction, or recycling to the point of obtaining gases and liquids of the original constituents of the material. Today's waste problems can be solved by the products that are in use today, with modifications in some cases to suit particular situations. There is no point in one waiting to say something revolutionary will be out tomorrow; therefore, one would be better to limp along on the obsolete equipment he has at present.

Often, existing equipment can be upgraded or used in conjunction with some of the newer techniques and equipment available, to make an overall very efficient system. For example, the 20 year-old Dumpster Hoist unit can handle containers from a new stationary packer.

The problem seems so complex one wonders "where does one begin; how can one distill a palatable brew from all the ingredients?" The first thing is to itemize the ingredients of the problem. Some of the factors which you will readily recognize are: (1) the refuse generating situation itself, (2) the actual refuse generated, (3) the storage and handling system, (4) transportation systems, and (5) the disposal system. In effect, these are all sub-systems within the overall system.

It is wise not to sub-optimize. Do not overly concentrate on one factor to gain efficiency in one small area, when at the same time one is incurring a great deal of additional expense or inconvenience in the total system. An outlandish example of sub-optimization could be the implementation of wheeled canvas container for collecting refuse from offices in a large complex, and attempting to use the same wheeled canvas container for collection of refuse throughout the entire manufacturing plant. The small container may be efficient in the office situation, but totally inadequate in the manufacturing area.

In reviewing the refuse generating situation, the overall plant layout has a great deal to do with the solution. For instance, is the plant a multi-story plant which generates varying quantities of refuse on different levels? If more refuse is generated on one level than another, is there easy access between floors; or, are present elevators and ramps crowded with production equipment?

In any plant, refuse should be categorized into solids, liquids, combustibles, non-combustibles, compactibles, and non-compactibles. To handle each of these refuse types, different equipment is sometimes required.

You are familiar with the various types of handling equipment available. In general, industrial and commercial refuse probably is handled by one of three general types of equipment shown in Figure 1.

The wheeled vehicle shown at the bottom of the figure is a Dinosaur, or tilt frame container handling unit. It is capable of handling containers up to approximately 45 cubic yards in a straight truck version, larger containers if trailer mounted. The figure shows the unit servicing a stationary packer container.

The machine in the lower left corner of the figure is a stationary packer which consists of a charging box in which refuse is placed and a

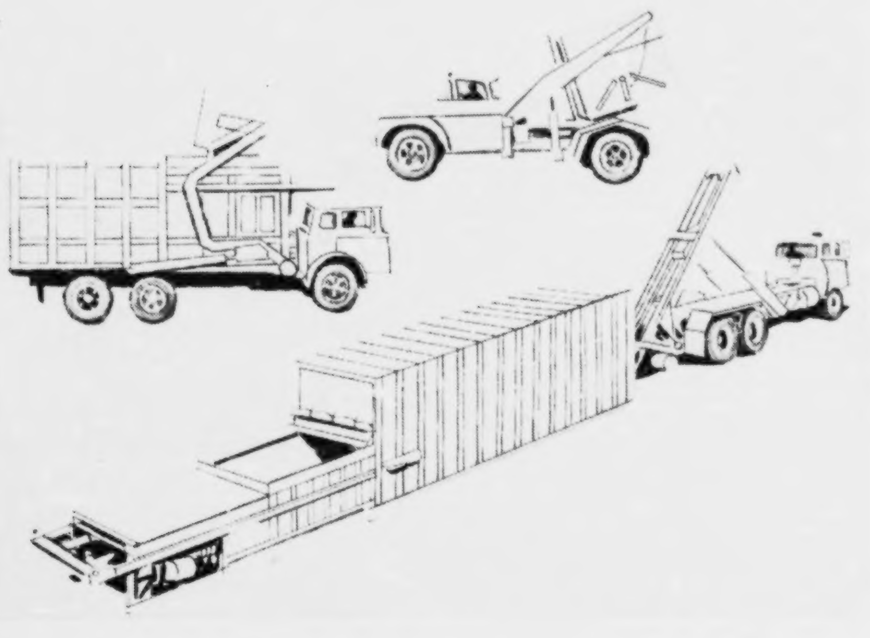

Figure 1

reciprocating head which pushes the trash into the large container. Here the refuse is so compacted to a fraction of its former bulk to give much greater economy in handling with a resulting decrease in the number of containers which must be handled.

The other vehicle is a Dumpmaster, which is a front loading detachable container handling truck, which includes a compaction body. In application, this truck normally services containers up to eight cubic yards capacity which are either placed where accessible by the truck or brought to the truck for dumping.

The unit in the upper right corner of the figure, is a Dumpster and is a truck mounted hoisting unit capable of handling containers up to approximately fifteen cubic yards and has been used widely for many years.

In most instances, waste is collected at a gradual pace rather than in large, bulky amounts in a short period of time. However, this is not always true. Dempster Brothers Inc. installed a system in one plant where the management claimed the reject material was less than five percent of the total production. However, wnen all the reject material was produced at one time, it was hard to believe the volume that came out of the plant during ten to fifteen minutes per day. The solution in that case was a large stationary packer system.

This particular material was extremely compactible and worked very well with the stationary packer system. A 40-yard container would be packed out in literally minutes. When this container was ejected at the landfill with the aid of a Push-Out head because of the extreme compactibility, the container and truck hauling unit were dwarfed by the payload which would re-expand to its original dimensions. But in general, material will be collected over a time period by some means of containerization.

In terms of liquid waste, it would be in tanks. In terms of sludges it would be in containers designed for handling these sludges. In terms of bulk or dry type waste, it might be in open top containers.

To some people, a container is simply a hollow cube. However, to the person planning and implementing the refuse storage and handling system, it is much more. For instance, what are

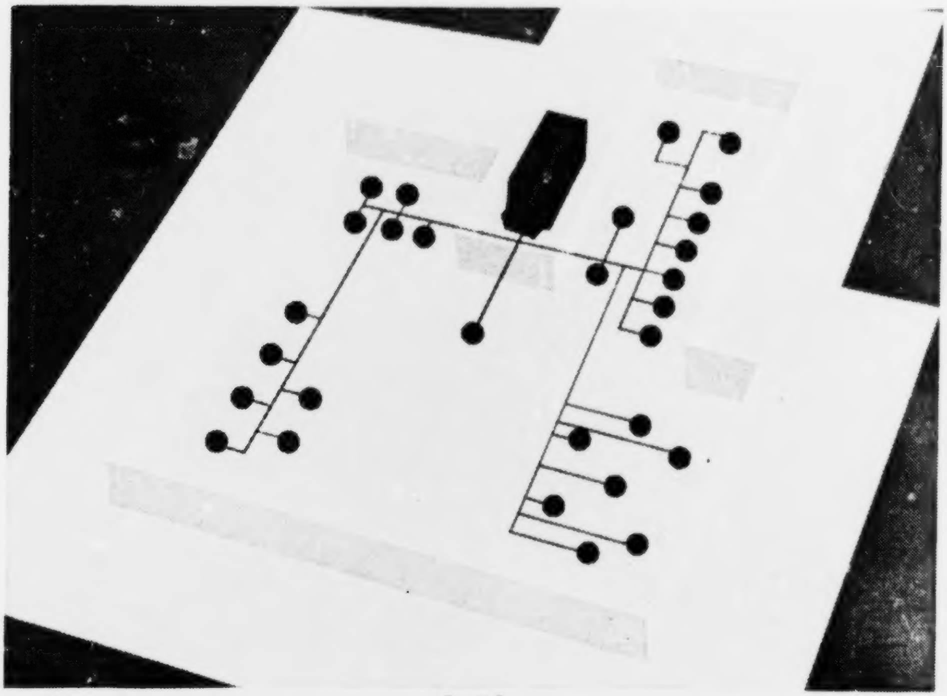

Figure 2

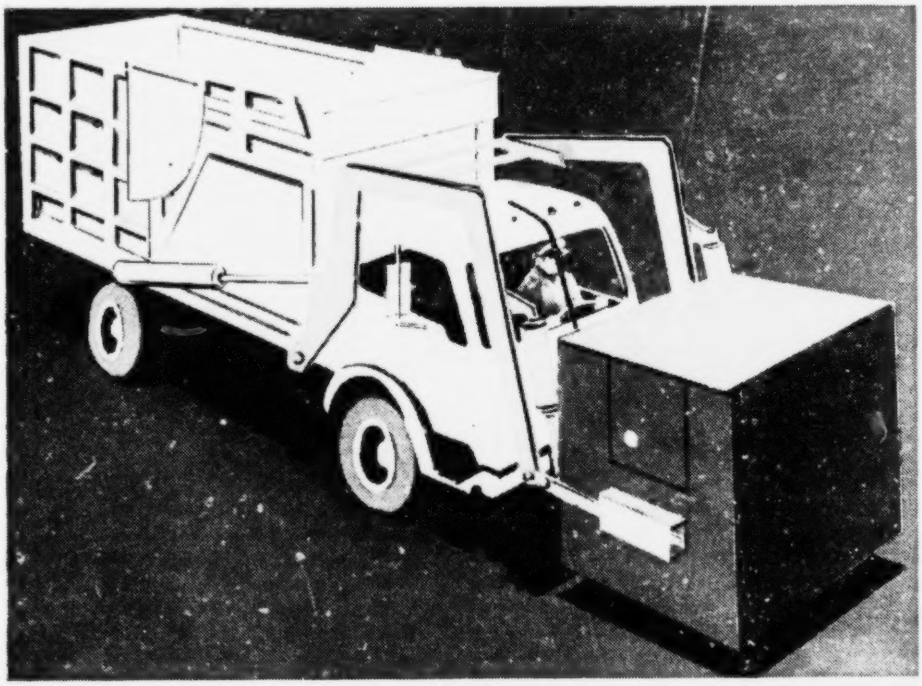

Figure 3

the assets of a metal container over a plastic container, or containers with lids versus containers without lids? In many cases there is a requirement for prevention of blowing or fire resistance. Though many plastics used in container construction can be fire resistant, they usually give off various gases in the halogen family; namely, chlorine when overheated. These gases can, of course, be dangerous.

Many times a container can be incorporated as part of the system itself. By adapting a neck to the top of a container it can be fitted directly to a dust collecting cyclone system or other types of dust collecting systems. Containers are frequently equipped with castors, flange car wheels or tow bars to facilitate incorporation into an inplant collection system. Liquid storage tanks for wastes are no longer simply tanks with a manhole which are filled from a hose or wheelbarrow. Frequently, these tank type containers are designed for pressures and fabricated to ASME standards. By equipping the tank with various fittings, it is possible to connect it directly into the process in order that the wastes flow into the tank under system pressure. Tanks may be equipped with heating coils to maintain viscous materials in liquid state for easy disposal. Tanks may be insulated for heat retention or equipped with a special lining such as polyvinyl chloride to prevent corrosion by difficult to handle liquids.

There are alternatives open to the user. He can review the possibilities of storing small containers within the plant for easy convenient use at each point of refuse generation. These containers can in turn be moved to a collection area where they are dumped into an on-site stationary packer to improve the payload for more efficient handling (Figure 2).

Stationary packers, used in conjunction with the in-plant containers, have enabled plants to increase the efficiency of their internal operation because of the greater flexibility offered in handling their own containers in the plant, as well as economical on-site storage of compacted waste versus large open top containers with uncompacted waste. There is also the intangible of

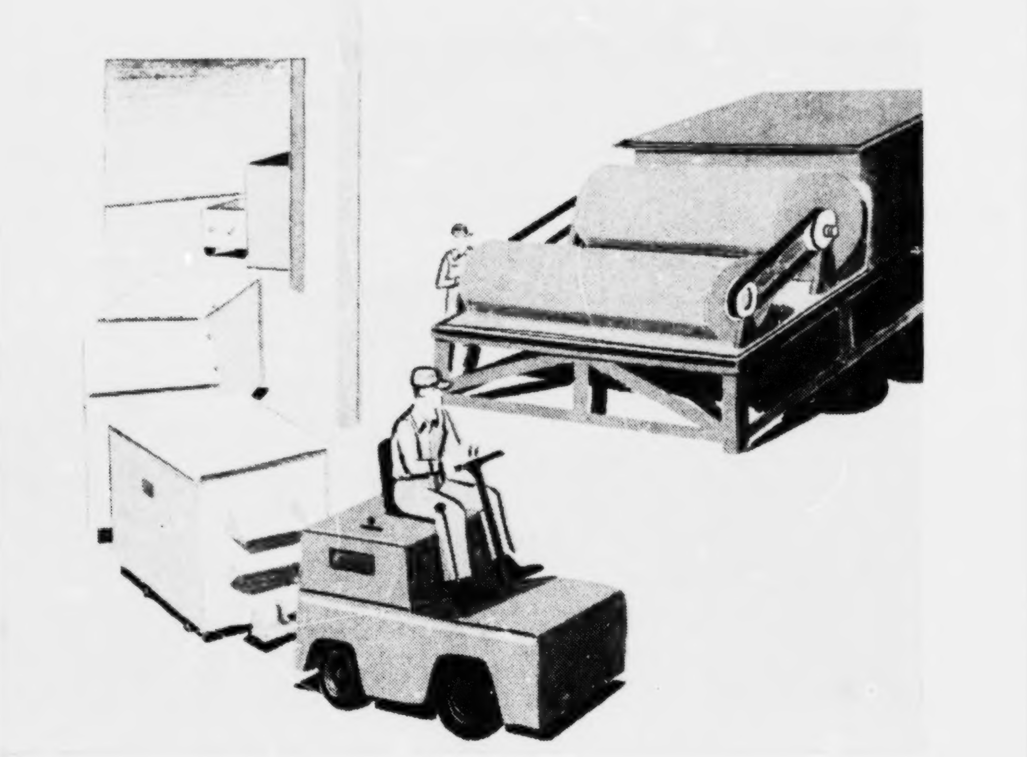

Figure 4

pilferage elimination when material is compacted into an enclosed container.

In order to eliminate moving containers of trash from floor to floor in a multi-floor plant for final collection in a stationary packer at the ground level, there may be an advantage in installing a chute outside the building feeding directly into a stationary packer on the ground. In this manner, the amount of traffic from floor to floor is reduced and the in-plant containers are kept closer to their station, where they can be returned quickly after dumping. Chute feeding can be as simple as a door on each floor into the chute or as elaborate as interlocks with automatic doors and dumpers for handling containers at each floor.

A stationary packer through a hole cut into an outside wall can save truck dock space, as well as keep refuse equipment out of the mainstream of plant traffic. Another thought in placing a stationary packer installation through a hole cut in the outside wall is the security of the building. In this type application, there is no need to have an outside entrance where there is some risk in employees or unauthorized personnel leaving or entering the plant.

Another alternative in containerization is the placement of containers either around the periphery of the building, where they can be approached by a front loading container handling vehicle (Fig. 3), or the use of an in-plant train system to pull these containers with their non-compacted payloads, to the front loader for compaction (Fig. 4).

In certain cases it may be desirable, when there are large amounts of waste produced or the waste is very bulky and non-compactible, to place containers as large as 40 to 50 cubic yards at refuse generation points. In a number of cases, plants already have container systems within them. In the past, these plants have been moving these containers to a corner of their own prop-

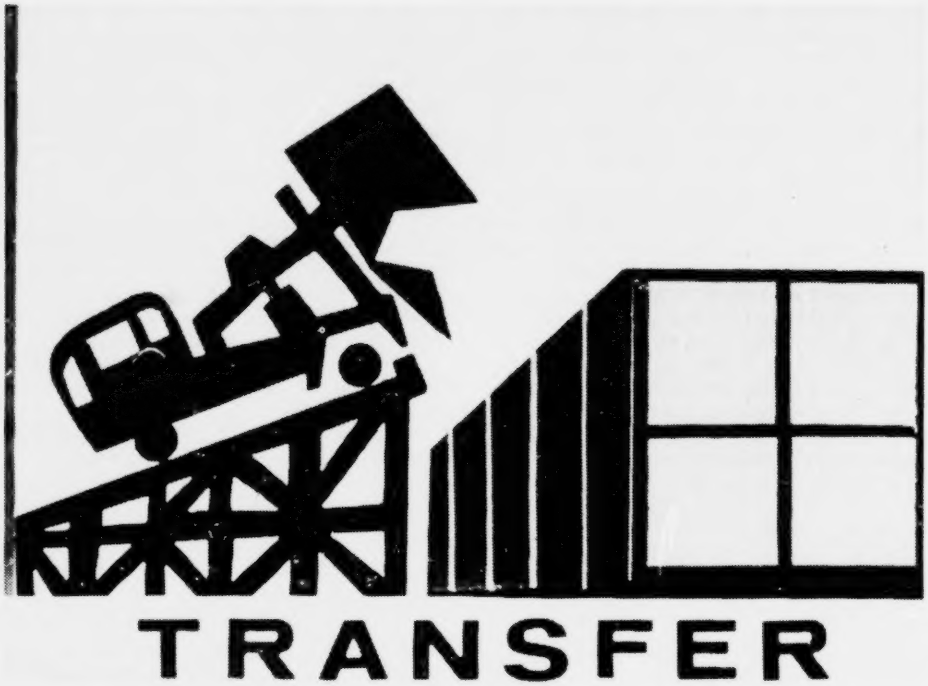

Figure 5

erty where they either had their own small disposal site or were burning their refuse on their own property. Since this has been outlawed, the first thought is that the system is obsolete because of greater hauling distances. This isn't so in many cases. The existing system frequently can be incorporated into a transfer station at the plant which has little effect on the internal material handling operation and does not require changing over containers or adding new containers for plant collection (Fig. 5).

Another factor to consider is the effect of a change in the refuse system on union problems. When a system is changed in the plant, it affects manpower requirements through the union contracts. Sometimes a company can eliminate manpower only by completely redesigning the jobs when the new handling system is installed. In other cases, if a more efficient handling system is installed, workers cannot be eliminated from their jobs because of previous contract commitments.

In the case of medium to large size facilities, another factor should be investigated when considering the storage and handling sub-systems. Should a facility consider purchasing their own equipment, including transportation vehicles, rather than contract some of the services with a private contract hauler? These factors are a combination of economic and service considerations, and have to be investigated locally in each case.

When evaluating — weigh cost total, not just the cost of equipment or services. What is the labor situation with a contractor with private equipment? What is the best collection time — night or day? Who provides containerization in each case? How important is the semi-independence of an on-site stationary packer system packing into large containers? How important is the factor of greater dependence when using smaller containers emptied into front loading vehicles? How dependent can one be on a contractor? How much back-up service is available from each contractor? How much access does one have to the disposal area with a contractor and with private equipment? If incineration is being considered, how does one plan to dispose of the non-combustibles?

In addition, when owning equipment, there is the flexibility to perform additional jobs within the plant, outside the area of refuse handling for which the equipment can also be utilized. What are the requirements for equipment utilization, capital, etc.?

It pays a facility to use the best talent available to investigate this refuse handling and storage problem. One cannot eliminate the problems of disposal from any discussion on waste. Disposal problems may be so complex that government agencies are involved, such as permission to dump in various areas, or permission to build incinerators, insofar as meeting smoke control and emission standards. Some areas of the problems of storage and handling can be delegated to various specialists in the field. However, even though there are specialists, some factors should be considered or reviewed very closely from one's own operational point of view. One of the main areas is the disposal site.

All too often in today's industrial climate, companies are being banned from burning or dumping on their own property and being required to dump or dispose of their waste in a commercial landfill or municipal landfill. When doing so, just what are the materials being disposed of in the fill itself? Are they possibly dangerous? What is the life of the fill? In discussing a possible contract removal of refuse, does one consider the length of time that he will be permitted to dump in that particular landfill at a given cost? Is there a possibility the landfill is short lived? Or, is there a possibility that the landfill is used by many other industrial and commercial customers which could, in effect, destroy a company's place to dispose of material which would again cause the company a headache?

In summation, laser beam disposal isn't here yet. Today's problems can be solved efficiently using the best combinations of the equipment available. Many times this can be combined with equipment already on the job to make an overall efficient handling system. Investigation is required to insure that the overall problem has been solved and that new problems have not been created.

A poor solution to storage, handling and disposal not only can cause inconvenience, but can cause extra out-of-pocket costs. It can mean poor utilization of floor space; it can mean down time because of jammed up material handling flow; it can mean liability suits because of poor performance in handling materials which require special care.

These factors, like the factors of any industrial problem, require a statement of the problem, setting down the various factors involved in the problem, choosing between feasible alternatives for an optimum solution and then implementing the solution.

Future Requirements for Collection Systems and Storage of Industrial Solid Wastes

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This paper is a critique on existing solid waste collection equipment and also projects what the requirements in this field will be in the future. That also includes mentally designing some equipment for the future as well. This is appropriate because the refuse collection operator is, by his own definition, the world's greatest engineer.

To conduct a critique, by definition, one must be critical of the existing state of the art. This is very difficult to do since the design engineers themselves are not at fault. The equipment has been designed and is available and is efficient in its operation. The manner in which it is operated is where the inefficiency lies along with the utilization of the equipment. The recent study by the National Academy of Engineering and the National Academy of Sciences, while basically sound and well conceived, recommends that additional effort be expended toward improving the compaction of collection equipment. This is not necessary, but additional emphasis must be given to the utilization of compaction equipment in solid waste practices.

Almost every compactor truck today is capable of achieving payloads far in excess of those which are legally allowable. Manufacturers are faced with necessity of complying with the weight laws established in each state, and they are generally defined as being 18,000 pounds per axle. There are variations and exceptions to this in some municipalities, but it is necessary to comply with the minimum allowable weight per axle in most instances, since the trucks do pass over county, state and federal highways at some point in the collection activities.

When referring to utilization of the equipment, the supposition is made that every municipality is served by compaction equipment. This is not the case at the moment, but everyone is attempting to upgrade their equipment to this point. However, to achieve maximum utilization of the vehicles, the vehicles should be routed to their maximum allowable capacity. If the vehicles are "routed" to the maximum allowable capacity, they will undoubtedly exceed this capacity 50 percent of the time. Also, when going across a highway patrol scale, loads hauled for the previous thirty days are not averaged out to determine whether or not the operator is liable for a fine, but rather, the specific load being weighed determines the liability. No concern is shown for the fact that the collection may have been made on the days after a holiday or that the collection might have been made in the rain or some other climatic condition may have caused the operator to pick up an excessive load that day.

California has been attempting for the last couple of years to get some exceptions made to this load limit to provide for just such a situation.

To date, this has been unsuccessful. The purpose in requesting the allowances has not been so that the vehicles can be deliberately overloaded, but rather, so that they can be routed closer to the ideal capacity of the vehicle. The amount of refuse generated in a given area is predictable, but it is only predictable if viewed over a relatively long period of time. At any specific moment or on any specific day, the amount of refuse generated from a given area can vary by 100 percent. Trucks cannot be operated at more than 50 percent of capacity from a routing standpoint, so attempts are made to achieve a trade-off and route somewhere near an 80 percent efficiency. Since refuse collection companies are charged with the responsibility of collecting whatever refuse is generated and stored on the specific collection day, operators run into considerable overtime on exceptional days when the amount of refuse generated is exceptionally heavy. One must look at the trade-off again of overtime necessitated by making additional trips or running the risk of the overload citation. Either of these work an economic hardship on the collection company itself.

The other question which involves the efficiency of a residential collection is the willingness of the public itself to cooperate. Residential collection, as opposed to commercial-industrial, is the most highly labor intensive aspect of the industry. The only way in which this intensity can be decreased is by increasing the efficiency of the individual collector. One of the greatest inefficiencies is the twice-a-week from single family dwellings. Vector Control can be accomplished by other means than the trade-off of efficiency, if the public so desires. The increasing trend towards the utilization of the plastic and paper sacks, plus the diminishing amounts of putrescible material in solid waste today, could mean that effective Vector Control could be achieved with once-a-week collection. The trend is toward twice-a-week collection at this particular time, but is not necessarily in the best interests overall. The twice-a-week collection contributes greatly to inefficiency in that 60 to 65 percent of the refuse collected is collected on the first collection day of the week. Due to this imbalance it is extremely difficult to even out the work load, and without balanced work weeks it is difficult to attract and retain the right type of personnel for this work. It also necessitates the work crews splitting their days off, in the case of a five day work week, and virtually guarantees excessive personnel. One of the requirements would be that the various health agencies reexamine the cost benefit involved of twice-a-week collection versus once-a-week collection for single family dwellings.

Another major contributor of inefficiency in residential collection is the backyard or side-yard service. This is primarily a matter of tradition, and a matter where the agencies or bodies which set the specifications for residential refuse collection seem to cater to the vocal one percent. Every study thus far performed indicates that the most efficient form of collection is the one-man truck combination. However, this man-equipment combination is not economic if backyard or side-yard service is to be provided. It is possible for a properly presented and documented case to be presented to residents so that curb side collection could be instituted. The vocal one percent will be extremely vocal, but they are only one percent, the benefit is for the remaining ninety-nine percent. Once-a-week collection and having the material at the curb will do a great deal towards improving efficiency, and at the same time raise the morale of the collection crews themselves. It is far more difficult to keep good residential crews than it is to keep commercial-industrial crews. It is a back-breaking and leg-tiring job, and the citizens themselves should be called upon to assist. By so doing, they can contribute materially to solving some of the labor problems currently enjoyed by the refuse collection systems.

The existing equipment, such as front loader compaction trucks, stationary compaction devices, and containerization, in the field of industrial and commercial solid waste management is sufficiently developed; that with the natural evolution and improvement of designs, no major problems exist as to hardware. Consequently, the requirements of the private contractor for the future do not deal with hardware as such. In the case of the industrial-commercial work, the biggest requirement is a recognition of the fact that every business or industry generates wastes. This fact should not be recognized after the facilities are completed and staffed and in operation, but rather, in the design stage. Generally speaking, the last thing considered in any design of an apartment house, retail store or industrial plant is the provision for the flow of solid waste material within the structure as well as provision for its storage pending collection. FHA requires that in any building, that is to be financed with any Federal funds, that a provision be made for solid waste storage. This requirement is met by designating a three foot by five foot space in the parking lot and calling that space "solid waste storage". This requirement, to a great extent, is all of the thought given to the subject. This meets the requirement — it does not meet the need. The curriculum of every architect and architectural engineer should include a study of solid waste systems including recycling, so that proper provisions for these processes can be made in their future designs. This study should not be only classroom, but actual on-site inspection of systems including visits to industrial plants, recycling plants, disposal sites, and a complete review of all of the existing hardware available today.

If these professionals can be made aware of this aspect of solid waste management and take these factors into consideration in their design of future office buildings, plants, and stores, great efficiencies can be achieved throughout. Contractors constantly run into the situation where the proper system cannot be installed in a plant or store due to a lack of planning in the original design. Space devoted to proper solid waste facilities certainly is not wasted. This space gives a higher return per square foot than any other space in the building.

Every practicing architect and architectural engineer should be required, as a matter of license renewal, to provide proof that he has attended these same courses so that at least within a three year period, every professional in the field would be cognizant of the need to design proper solid waste facilities into their projects. Building departments throughout the country would assist in the development of this idea by making it a requirement that before construction approval is granted, for any building in which the end use is known — that a comprehensive plan for the handling of solid waste be included. Particular emphasis should be made on the segregation of materials at the source, so that recycling will become a reality rather than a buzz work.

Existing technology and the hardware, which is presently designed and in use, is capable of handling solid waste, as it is generated today and in the foreseeable future; and that, aside from mechanical improvements and natural evolution, no major breakthroughs will be made in collection or storage of waste in the foreseeable future. Simply because vehicular transport has traditionally been used, it does not mean that it is not the most efficient method. Hardware engineering is not the requirement — human engineering is the requirement. Only through improving efficiency can the overall system be improved, and this improvement in efficiency must start with an awareness by the people who utilize the services of the industry. Given this awareness, the industry can respond.

Collection and Storage Systems for Non-Aqueous Liquid Wastes

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Consultant
and
DAVID E. MARCHAND
COPE, Inc.

INTRODUCTION

The need for effective collection and storage systems for industrial wastes is a result of the recent developments in the pollution control field. Previously, many liquid industrial wastes have been disposed at their source through expedient methods such as open dumping and open burning. With the advent of greater regulation and enforcement of environmental standards, these practices are being abandoned in favor of a centralized approach to the waste disposal problem.

If a centralized system is to be an effective solution to industrial waste disposal, a practical method of transferring wastes from their source to a central facility must be devised. Several criteria should be considered for any collection and storage system:

1. The system should be compatible with the industry it serves.
2. The system should not contribute to environmental pollution.
3. The system should consider adequate safety controls and procedures.
4. The system should afford the lowest cost consistent with the above objectives.

The above criteria impose certain restrictions on any proposed method of collection and storage, but they are important considerations if a satisfactory long-term solution to the waste disposal problem is to be found.

Categorizing Wastes

It is important to consider the various types of wastes that may be handled by a collection and storage system, and to categorize them according to various functional requirements. In this regard, the collection and storage system should be considered an integral part of the whole industrial waste management system.

In categorizing wastes, consideration should be given to the following factors: handling problems, such as suspended solids plugging transfer lines; incinerator criteria, if this is to be the ultimate disposal method; and also, safety factors.

Basic Types of Wastes

The basic categories of wastes that have been developed for a central incineration facility are listed in the following table. Each of these categories was developed from a consideration of storage and incineration requirements. The following description should develop an appreciation for the wide variety of industrial wastes to be considered:

1. **Non-Viscous, Low Ash Liquids**

   These materials consist primarily of residues from tank cleaning operations, absorber oils, and contaminated or off-specification products.

2. **Viscous Liquids and Tars**

   Various waxes, asphalts, polymers and copolymers are contained in this category.

3. **Chlorinated Liquids and Tars**
   These materials are produced as by-products from the manufacture of vinyl chloride, insecticides and chlorinated solvents.
4. **Semi-Aqueous Liquids**
   Principally, aqueous wastes containing toxic compounds that are unsuitable for biodegradation.
5. **Semi-Solid Wastes**
   Wastes containing a high percentage of suspended solids, including sewage sludge, API separator sediments, and acetylene coke.
6. **Solvents**
   Contaminated solvents such as naphthas and alcohols.
7. **Toxic or Hazardous Wastes**
   Various pyrophoric or high toxic wastes such as cyanides.

TABLE 1
Typical Waste Categories

Type	*Description*	*% H_2O*	*% ASH*	*BTU PER LB.*
1	Non-viscous, low ash liquids	0 - 10	0 - 10	15 - 20,000
2	Viscous liquids & tars	0 - 50	0 - 10	10 - 20,000
3	Chlorinated liquids & tars	0	0 - 10	1 - 10,000
4	Semi-aqueous liquids	80 - 99	0 - 5	0 - 2,000
5	Semi-solid wastes	0 - 50	20 - 50	5 - 10,000
6	Solvents	0 - 10	0	10 - 20,000
7	Toxic, corrosive or hazardous	0 - 10	0 - 10	5 - 10,000

Collection Systems

The above types of wastes determine the facilities best suited for transportation of the wastes, whether it be by truck, rail, barge or pipeline.

When considering transportation systems, convenience and ease of handling is an important factor. Specialized tank trucks are available which allow efficient loading and unloading of waste materials.

Vacuum trucks have a relatively small capacity but have the ability to load almost any one of the wastes mentioned. Their unique advantage consists of pumping the liquid waste through internal vacuum suction rather than relying on external pumps. Actually many wastes, particularly Category 5 - Semi-Solids, cannot be pumped at all without special equipment.

Where large volumes of liquids are involved, bulk transportation systems, such as tank trucks, cars, or barges, can be utilized. Barging is usually more economical if the waste is to be shipped a distance of over fifty miles, and then only when large volumes are considered. In any case, bulk transportation costs are relatively low with respect to the costs of ultimate disposal, so that fairly long shipments can be considered and still be economically feasible.

Pipeline transportation is still another method that can be feasible under certain special conditions. If industry is grouped closely together, as in a large scale industrial development, this method can be practical; although the separation of wastes into distinct categories for later incineration is impossible if a common system is used. However, the possibility of moving individual large volumes of waste by "over the fence" pipeline is certainly practical if the disposal facility is in close proximity to the waste producing industry.

If the waste producing industry utilizes a separate transportation service company, as will usually be the case, consideration must be given to reliability and experience in transporting waste materials. Usually in any industrial community, local firms are available that have been dealing with this problem on perhaps a smaller scale for quite some time. These firms should be the first ones to be consulted, since they are usually familiar with the various types of waste materials and the problems associated with transporting them.

It is important for both the producing industry and the waste disposal facility to work closely with the transportation firm to develop scheduling procedures. In order to minimize in-plant storage facilities, a workable pick-up schedule must be developed, taking into consideration waste production rates and the time and distance to the disposal facility.

Loading Facilities

The common practice today, especially in the process industry, is to store wastes in pits or lagoons for periodic removal. Actually, in many cases dumping in open pits is the only method of disposal. Such a practice not only utilizes valuable land, but creates a fire hazard with its attendant air pollution and also contaminates water sources through surface runoff and leaching.

This method of earthen storage can be satisfactorily utilized, but close attention must be given to sub-surface soil conditions, and provision for dikes must be made to prevent contamination of surface run-off. A plastic liner can also be incorporated to prevent contamination of groundwater sources. If surface storage is utilized, care must be exercised to store only high flash point and low volatility liquids.

These storage pits are usually located some distance from process facilities for obvious reasons, so that pumping and loading facilities are normally absent. In this case, the vacuum truck is the only system that will work satisfactorily. These specialized tank trucks have the capability of pumping directly out of an earthen pit and have proved so satisfactory that the majority of industrial waste liquids are moved this way.

Where bulk transportation facilities are utilized, tankage and a loading rack must be present. This is only economical if large quantities (50,000 gallons per month) are being shipped. Sufficient storage must be provided to completely load the tank car or barge, which means as much as 10,000 bbls. may be required. Usually a separate loading rack will be required, since most companies would be hesitant to risk the possibility of contaminating their products with wastes.

Pipelined wastes require little or no loading facilities, since generally the waste producing process will be connected directly to the pipeline.

Other sources of wastes such as sumps for used lubricating oils and API separators can be cleaned directly by a vacuum truck. Here again the vacuum truck's versatility is demonstrated by its ability to load directly from the waste-producing source.

Storage and Unloading Facilities

At the ultimate disposal site, which for this discussion is assumed to be an incineration facility, wastes must be unloaded from the transportation facility into storage.

It is important from the standpoint of handling safety and efficient incineration, that each different waste be separately identified so that it may be routed to the proper storage location. A system of color-coded tags has been suggested, so that the receiving operator may handle the waste in the most appropriate manner.

Category 1, 4 and 6 wastes can be pumped directly to storage in API tanks if proper operating procedures are followed. Standards as described in the National Fire Code should be followed for the appropriate class of liquid, and particular attention to the proper grounding of tank trucks and the utilization of flame arrestors on tankage should be given.

Viscous liquids and tars can usually be transported in a hot liquid state in a tank truck. These materials are then pumped via steam traced lines to a steam heated tank. Steam jets must be available at the unloading site for tars that have cooled to the point of being non-fluid.

Semi-solid wastes can be most easily handled by temporarily dumping them into a sump for transfer to aboveground storage or pits. These wastes require such specialized equipment, such as Moyno Pumps that the truck can be most quickly unloaded by temporarily transferring the waste to a sump.

Chlorinated wastes and corrosive, toxic or pyrophoric wastes should be handled with special care as is appropriate for the specific material. For example, isocyanates can be safely handled if care is taken so they do not come in contact with acid wastes, causing the evolution of toxic hydrogen cyanide.

Storage facilities for this type of waste may consist of plastic lined steel tanks to prevent corrosion. In certain cases, it may be necessary to blanket the liquids if unstable compounds are present. For these wastes, the usage of fibreglass piping and epoxy pumps is highly recommended.

For any storage system, it is important to follow a periodic inspection procedure for all tankage, valves and piping. Tankage should be inspected regularly for corrosion and proper function of safety equipment such as vents and spark arrestors. Application of sound engineering and design practices will avoid most problems in this regard.

CONCLUSION

At this point, it should be apparent that the collection and storage of industrial wastes is no simple matter. The problem requires careful application of all available techniques in the field of materials handling to achieve a workable solution. We foresee a sizeable expansion of the industry involved in this activity, with the result that more advanced techniques will soon be developed.

It is our opinion, however, that with presently available technology, applied in an intelligent manner, this problem can be solved on an economical and efficient basis, so that all industries can benefit from central collection and disposal of their by-product wastes.

Transportation Systems For Industrial Solid Waste

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and
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INTRODUCTION

As part of a feasibility study for a central industrial incineration facility to serve an industrial complex of ten major industries, the three potentially available modes of transportation (i.e., barge haul, rail haul, and over-the-highway type vehicles) were optimized as to operation and containerization.

This paper presents general data on the types and quantities of waste materials encountered, and existing industry transportation systems utilized. The methodology used to develop alternative transportation systems design is summarized. Alternative transportation systems so developed are discussed, and costs are compared.

Background

As part of the initial investigations, the ten industries were surveyed to evaluate existing storage and transportation systems as well as to determine waste quantities and characteristics. A variety of solid waste materials were encountered, including biological sludges from industrial wastewater treatment plants, solid tars, industrial refuse, liquid organic residues, various other process liquid residues, and numerous drums and small containers. Tables 1 and 2 are summaries of the various types of materials encountered and the approximate quantities to be hauled.

TABLE 1
Summary of Annual Quantities of Industrial Refuse for Transportation

Item	*Volume* *Cubic Yards/Year*	*Weight* *Tons/Year*
Paper, Rags, Trash	128,000	12,800
Bulk Lumber	16,500	3,300
Garbage (Cafeteria wastes)	1,480	800
Plastics, Tars (55 gallon drums)	3,310	2,630
Filter Media & Cake	5,750	5,430
Dewatered Activated Sludge	6,500	6,500
Total	161,540	31,460

Refuse and solid wastes from all of the industries surveyed were transported in dump trucks, semi-trailers, or portable boxes. Liquid residues were transported by pipeline, in drums, by portable tanks, tank trucks, and tank trailers of various capacities. The pick-up and hauling of these various waste materials from the production areas was found to be confined to day-shift operations, with the majority of waste materials generally being hauled on a 5-days-per-week schedule. However, certain waste materials, because of the quantity generated, were occasionally hauled on a 6-day or even a 7-day week.

TABLE 2
Summary of Annual Quantities
of Industrial Liquid Residues for Transportation

	Volume, Thousands of Gallons per Year	
Item	*Heated Containers Required*	*No Heating Required*
Organic Liquid Residues,		
Non-Corrosive	2,518	2,714
Corrosive	135	2,710
Hydrocarbon-Water Residues,		
Non-Corrosive	0	660
Total	2,653	6,084

Evaluation of Alternative Transportation Systems

The principle considerations used for the evaluation of each of the possible transportation modes included: 1) the ease of coordination with existing plant operations; 2) the amount of rehandling of waste materials at the incineration facility; 3) the flexibility in economics of handling materials which could require corrosion-resistant containers or heated storage; 4) the practicability of handling reactive liquid residues which would require special containers; 5) the speed of delivery of materials which could deteriorate or produce offensive odors if stored for more than several hours; 6) desire to maintain a minimum accumulation of materials which could present a fire hazard; and, 7) desire to reduce the amount of in-plant storage and handling to a minimum.

It was felt that an optimum economic operating schedule for the transportation system would be a 7-day-per-week schedule. This would minimize in-plant storage and make maximum use of the available transportation equipment. It was also felt that additional economies in equipment requirements, on an initial capital cost basis, could be realized by operating the system on a continuous 24-hour per day basis. Since most of the industries operated on a continuous 24-hour basis, a 24-hour waste pick-up schedule would not conflict with plant production, and containers would be sized to handle the waste accumulation between pick-ups.

In order to provide a dependable and flexible materials handling system, a containerization approach was utilized in the design of all alternative transportation systems. This containerization approach consisted of providing wherever possible, standard pull-on boxes, containers or chassis-mounted tank trucks which are readily available. For example, normal industrial refuse such as paper and boxes, would be brought to stationary compactors located adjacent to the generation source. These stationary compactors would accomplish approximately three-fold reduction in the volume of material to be hauled. Liquid residues would be shipped in standard 3,000, 4,000, or 5,000-gallon tanks depending on the transportation system selected. Bulk materials, such as activated sludge, filter cake and large size lumber, would be moved in portable, open boxes of various capacities, up to 40 cubic yards. Drums and fiber-pak containers would be sorted at designated areas and transported on special multi-level drum trailers.

If at all possible, the container would be stored directly adjacent to the production unit, or as close thereto as possible. With the proper use of ramps or pits, these containers could be gravity loaded and unloaded. Specialized containers, for protection against corrosion or for heated storage of materials, would be provided only where specifically required. Waste from the production area would be discharged, or brought to the container in which it would be accumulated until the scheduled pick-up. This type of system would probably minimize the amount of material handling by plant personnel. Within production areas where space was at a premium, it was felt that a centralized transfer loading area of modest size might be necessary to minimize in-plant handling. Naturally, when considering either rail or barge hauling, some type of centrally located transfer station would have to be provided. An evaluation of the various geographic locations of sources of the waste materials within the industrial complex indicated that three transfer stations would be necessary for either rail or barge hauling. In either case, these transfer stations could be located at the same sites.

Reactive residues, such as chlorinated organic liquids, would be kept segregated in shipment, and the same container would be reused for the same material. This would minimize the necessity of cleaning tanks, and reduce the possibility of undesirable, and perhaps hazardous, chemical reactions resulting from hauling other waste materials in these containers.

Ultimately, filled tanks and boxes would be moved by truck, from within the various industrial production areas, to railway flat cars, rive barges for river transportation, or highway vehicles. For each mode of transportation, containers permanently mounted on a trailer chassis were compared to portable, pull-on containers. In either case, portable boxes would be provided for industrial refuse. An economic analysis of methods of transferring these containers to either rail cars or barges indicated that the use of heavy duty cranes were more costly than driving the containers onto either the barge or rail car. The truck would then leave the container which would be secured and subsequently transported to the center industrial incinerator facility.

As part of each transportation scheme, the time required to move a filled container from the industrial plant or the transfer station to the potential incinerator site and return was used as one of the major criteria in determining the number of containers which must be provided. The time that a container is tied up in transit to and from the incinerator facility must be matched with additional container storage at the production area. The cleaning and repairing of individual containers could be made without disrupting or significantly reducing the capacity of the transportation system if these functions were done at the incinerator site after unloading. The use of a containerization concept also allows for additional containers, of special design, if necessary, to be added as future needs change.

Barge Transportation System

Figure 1 shows the pick-up points (transfer stations) and typical operating schedule for barge movement of containers to the potential incinerator site. By operating a tow boat continuously, it would be possible to make daily pick-ups at each of the three transfer stations. A sufficient number of containers would be provided to allow for a minimum of two days' waste storage at each transfer station. Consideration would have to be given at these transfer stations to provide for adequate storage and protection of these waste containers for up to two-day periods. Such considerations would include, among others: fire protection and alarms; safety precautions relative to storage of hazardous materials; compliance with federal and state laws regarding protection to the public against accidental discharge of waste materials; and protection against vandalism.

The type of barge to be utilized would consist of a specially constructed, reinforced, open-deck barge. The containers would be end-loaded onto the barge by driving trucks over a floating ramp which would serve as a temporary connection between a dock and the barge. The containers would be unloaded off the barge in the same fashion. After placement on the barge, each container would be tied down by the use of special fittings on the barge deck. Consideration was given to the proper loading sequence to minimize unbalanced load conditions. Evaluation of the potential capacity of the barge showed that no difficulties with loading should be anticipated.

Two barges, 32 feet wide by 82 feet long, would have to be provided. Figure 2 shows the general arrangement and type of containers which were considered necessary for the type of waste materials to be picked up at each transfer station. An evaluation of the man-power requirements for barge loading and unloading exclusive of the tugboat crew showed that a minimum crew of two men per shift, operating on a three shift-per-day basis, 7-days-per-week would be required.

The evaluation of the feasibility of barge hauling indicated that such a system would be affected by adverse river conditions and would be relatively inflexible for meeting short duration, peak demand situations. The potential also existed for serious adverse publicity should one of the barges experience an accident on the river.

Railroad Transportation System

Railroad movement was considered feasible for the same transfer stations used for the barge haul system. Figure 3 indicates the probable routing for the potential incinerator site using rail haul.

Flat cars, which would be 85 feet long, would be modified to carry 4-20 foot containers, either tanks or boxes. A minimum of three days, on the average, was found necessary to ship a container and return it to the industrial source. It was, therefore, necessary to provide for a sufficient numbers of containers to allow four days' storage of specific material which would be shipped by rail. Consideration of rail haul also showed that only relatively unreactive material which could be stored either at the plant site or at one of the transfer stations would be suitable for rail hauling. The other industrial solid wastes which would be either reactive or generated in sufficient quantities to prohibit four days' storage would have to be transported to the incinerator site by highway vehicles. It was also felt that railroad transportation offered no operating advantage with respect to flexibility or dependability as neither the industry nor the incinerator complex would have control over the time required for transportation and scheduling of pick-up and delivery of the waste materials.

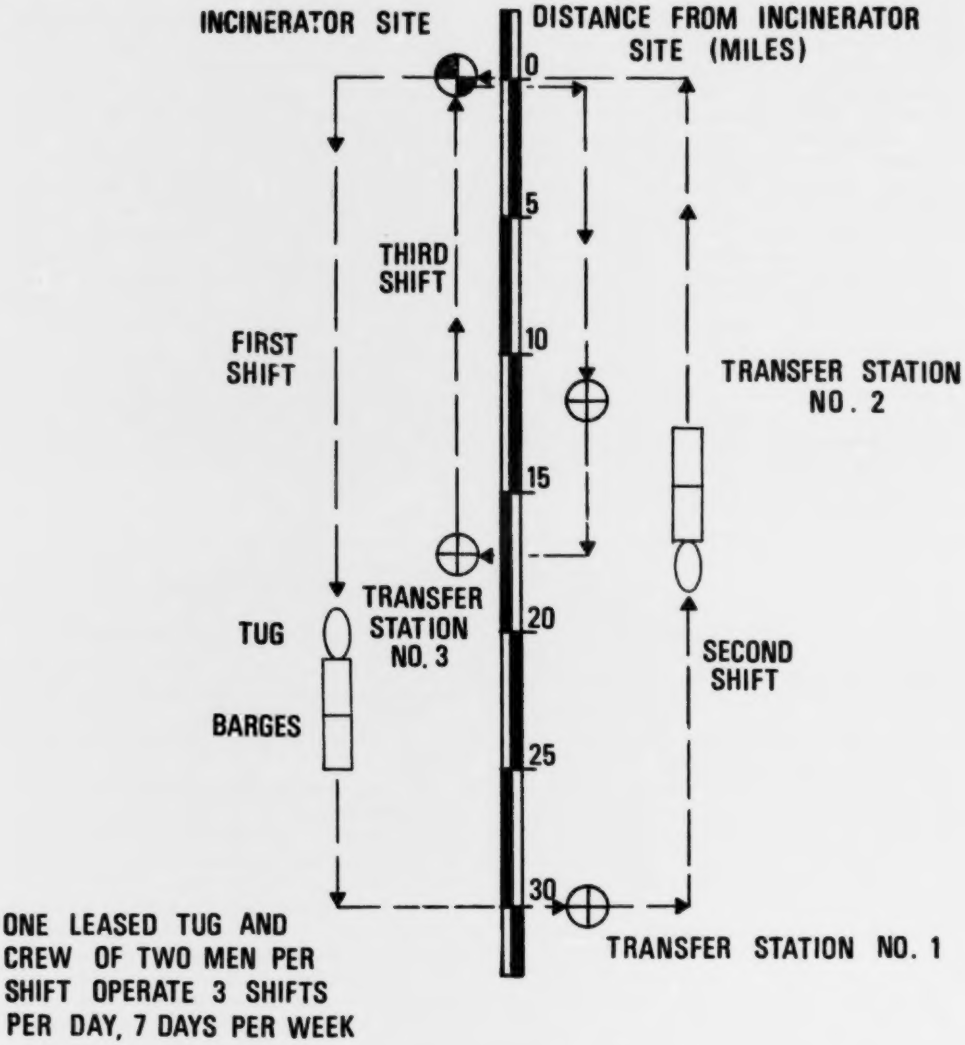
INCINERATOR SITE
DISTANCE FROM INCINERATOR SITE (MILES)
0
5
10
15
20
25
30
THIRD SHIFT
FIRST SHIFT
TRANSFER STATION NO. 2
TRANSFER STATION NO. 3
TUG
BARGES
SECOND SHIFT
TRANSFER STATION NO. 1
ONE LEASED TUG AND CREW OF TWO MEN PER SHIFT OPERATE 3 SHIFTS PER DAY, 7 DAYS PER WEEK

Figure 1: Barge Pick-Up Locations and Operating Schedule

Highway Vehicle Transportation System

Within this approach, two alternative vehicle systems were considered for highway transportation of the industrial solid wastes. In both cases, a maximum legal weight limit of 70,000 pounds was utilized to reduce the number of trips per day to a minimum. Truck drivers would pick up the loaded containers from a designated area within the industrial production facilities and return these empty containers back to that area the same day. Thus, only enough containers to handle one days' waste volume was necessary. The number of trucks required was also minimized by assuming a 24-hour, 7-day-per-week operating schedule.

The first alternative investigated for highway vehicle transportation involved a system where conventional 5,000 gallon tank trailers and 53

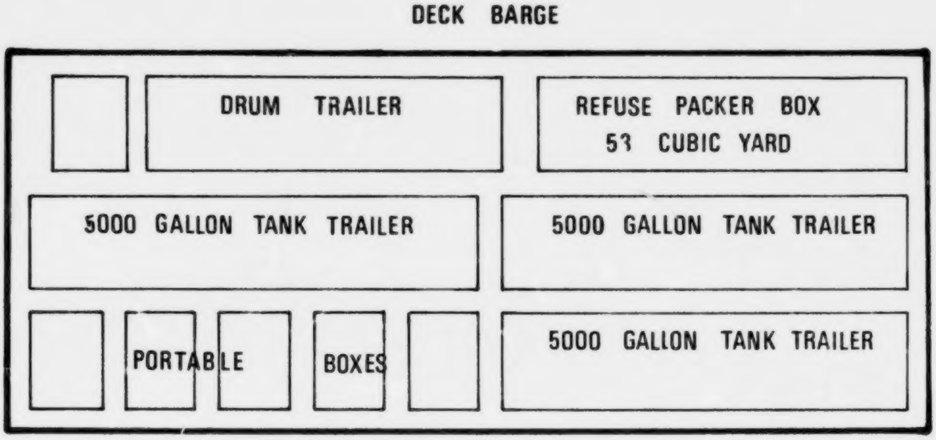

Figure 2: Typical Containerized Barge Load

cubic yard packer refuse trailers on fixed trailer chassis would be provided. The second alternative consisted of utilizing 4,000 gallon portable tanks and 30 yard packer boxes. The containers to be used for the second alternative do not have a trailer chassis under them unless they are actually being transported between the point of waste generation and the incineration facility. When these containers are to be shipped to the incinerator facilities, a pull-on type tractor trailer would hydraulically pull the container onto the tractor bed and lock the container for shipment.

Economics

In comparatively evaluating the economics for the three modes of transportation, certain factors were felt to be of significance. These factors were: 1) lowest initial capital expenditure; 2) lowest cost for future addition; 3) lowest operating cost; and, 4) greater container availability.

Rail transportation was initially considered economically feasible because of the high volume and frequent movement of rail shipment within the study area. However, preliminary rate information from the railroads involved in the study indicated that the annual cost of shipping refuse and residues from the various transfer stations would be approximately $600,000. This charge did not include the expenditures for providing the necessary rail spurs into the incinerator site, the use or lease charges for the special rail flat cars, labor charges for loading and unloading the rail cars, the capital expenditure necessary for the portable shipping containers, or the transportation charges associated with shipping the waste materials not hauled by rail.

The most economical barge system would use 3,000 gallon containers without a permanently attached truck chassis. The initial capital expenditure for this system was estimated to be $796,000 not including dock facilities or leasing of the tug boat. The annual operating cost was estimated to be $69,700 plus $105,000 for the lease of boat and crew. An initial comparison of costs of transportation for barging with rail hauling showed that railroad transportation was not economically attractive.

With respect to the highway vehicle transportation system, the first alternative evaluated, which consisted of trailer mounted conventional tank trailers and packer refuse trailers indicated a capital cost of $405,000 with an annual operating charge of $43,000. With respect to the second alternative evaluated where portable tanks and packer boxes were used with a hydraulically operated pull-on chassis, the initial capital expenditure was $341,000 with an annual operating charge of $35,300.

Table 3 is a summary tabulation showing the various comparative costs between the two alternative highway transportation systems and the barge haul system. Since the initial rail haul charges were significantly greater than any of the capital expenditures indicated for other systems,

TABLE 3
Cost Summary of Alternate Transportation Systems

Alternatives:												
Description	Portable Tanks on Deck Barges and some road vehicles			Tank Trailers on Deck Barges and some road vehicles			Highway Movement with Truck Trailers			**Highway Movement with Portable Containers**		
Equipment	Size	No.	Cost	Size	No.	Cost	Size	No.	Cost	Size	No.	Cost
Barges	26' x 90'	7	$280,000	32' x 82'	7	$300,000			$			$
Refuse Packer Boxes	30 yd.^{3}	12	144,000	53 yd.^{3} 30 yd.^{3}	8 2	168,000	53 yd.^{3} 30 yd.^{3}	5 2	114,000	30 yd.^{3}	8	96,000
Mild Steel Tank Trailers				5,000 gal.	13	156,000	5,000 gal.	6	72,000			
Stainless Steel Tank Trailers				5,000 gal.	5	135,000	5,000 gal.	4	108,000			
Mild Steel Portable Tanks	3,000 gal.	19	95,000	4,000 gal.	2	12,000	4,000 gal.	2	12,000	4,000 gal.	10	65,000
Stainless Steel Portable Tanks	3,000 gal.	8	120,000							4,000 gal.	4	64,000
Special Trailers	45,000 lbs.	3	42,000	45,000 lb.	1	14,000	45,000 lb.	1	14,000	45,000 lb.	2	28,000
Tractors, Gasoline Powered	70,000 GVW	4	50,000	70,000 GVW	4	50,000	70,000 GVW	2	25,000	70,000 GVW	2	25,000
Drum Trailers		4	10,000		4	10,000		4	10,000		4	10,000
Fork Trucks	5 Ton	2	20,000	5 Ton	2	20,000	5 Ton	2	20,000	5 Ton	2	20,000
Portable Boxes	Misc.	26	32,000	Misc.	28	32,000	Misc.	19	27,000	Misc.	14	30,000
Pick Up Truck		1	3,000		1	3,000		1	3,000		1	3,000
Total			$796,000			$900,000			$405,000			$341,000
Annual Operating Costs			$ 69,700			$ 81,300			$ 43,000			$ 35,000
Additional Required Facilities	(4 Docking Facilities)			(4 Docking Facilities)			Possible some loading ramps			Possible some loading ramps		
Non-owned Facilities	(1 Tug Boat)			(1 Tug Boat)			(None)			(None)		
Annual Cost of Non-owned Facilities Including Operating Labor	$105,000			$105,000								
Incinerator Hauling Labor Force Required, not including Supervision	17 men			17 men			5 men			5 men		
Comments: Flexibility	**Poor**			**Fair**			**Excellent**			**Excellent**		
Reliability	**Fair**			**Good**			**Good**			**Excellent**		

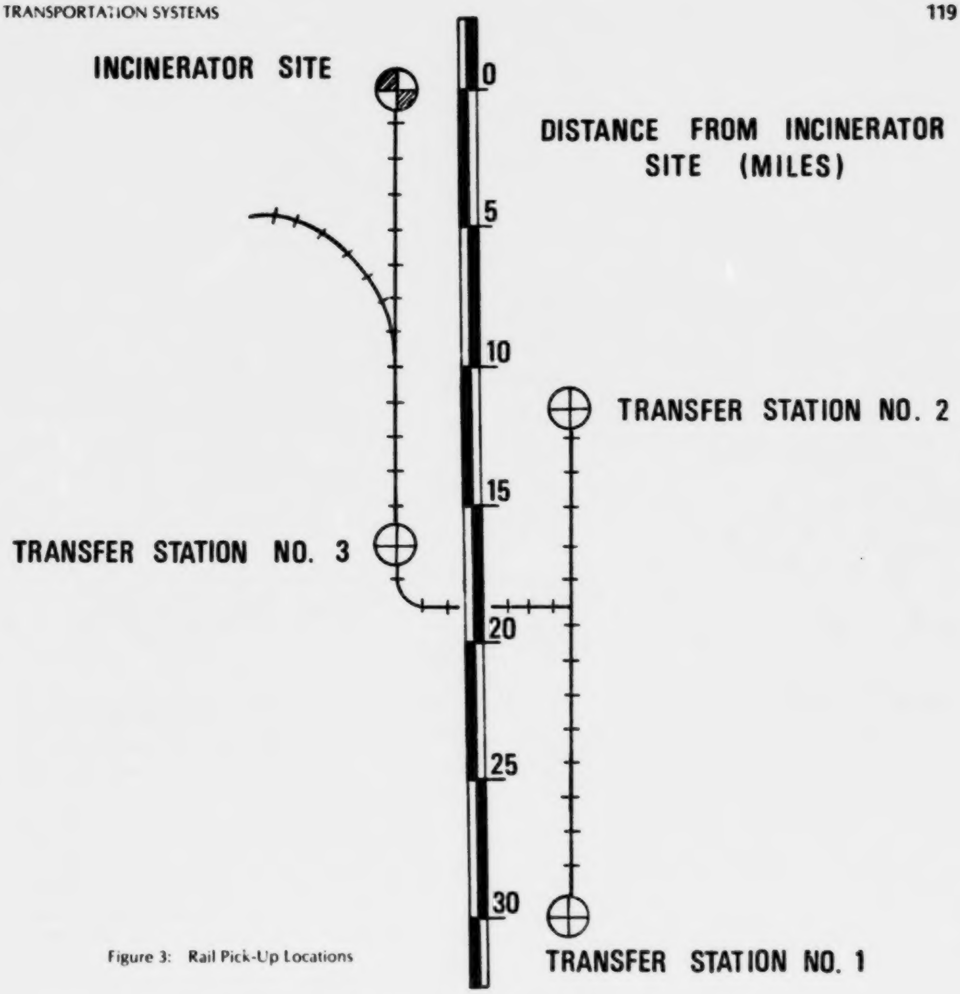

Figure 3: Rail Pick-Up Locations

a detailed economic analysis for rail haul is not included.

Table 3 also shows the number and sizes of containers and the type of equipment to be provided for each alternative investigated for barge and highway vehicle transportation. Manpower requirements are also included with a summary rating of each alternative with respect to flexibility and reliability. As can be seen with the criteria specified for the evaluation of the various transportation systems, the highway vehicle system utilizing portable tanks and packer boxes with a hydraulically operated pull-on type truck chassis was the most economical method of transportation.

SUMMARY

The transportation system was design for 24-hours-per-day, 7-days-per-week collection to obtain maximum utilization of manpower and equipment. Economics were apparent in using large waste containers which could be hauled on pull-on trailer chassis, thus reducing the number of trailer chassis to a minimum.

The results of this feasibility study indicated that, for these particular conditions, a highway vehicle transportation system would be the least costly to set up and run when compared to barge or rail systems. In addition, the highway system had the greatest degree of dependability and flexibility.

Industrial Waste Utilization and Disposal

HARRY KLETTER
Industrial Services Company of America

INTRODUCTION

This paper presents some of the growing problems in the field of solid waste disposal and at the same time offers the only obvious solutions readily available at this time. These are basic, proven methods and equipment for the efficient, economic handling of solid waste. At this time research is being conducted on local, state, and federal levels as a result of the passage of the Solid Waste Disposal Act of 1965. This was a belated but welcome step in the right direction to the solution of an immense, universal problem.

The environment is being adversely affected by one major problem. That problem is "waste generation".

Matter can neither be created nor destroyed. This is a basic law of science. When matter is changed into another form for an advantage, the desired form of matter not only results, but also generates waste results. This waste is broken down into three forms, i.e., solid, liquid, and gaseous.

Most emphasis recently has been placed on the problem of waste in its gaseous form, air pollution. The reason this form of waste has been singled out is quite obvious. The cases of respiratory ailments in industrial cities have been increasing at a deadly pace, and damage is done by fine silt on houses, cars and other property.

What about the solid form of waste? Why isn't more emphasis being placed on this problem? As more action is being taken to reduce the air pollution, such as shutting down incinerators, the solid waste problem will worsen.

Why not put more emphasis on the solution to the solid waste problem since any degree of success will also ease the air pollution problem?

The third form of the waste problem is liquid. These sludges and other chemical liquid forms are being piped into our rivers and streams doing unimaginable harm. The practice must eventually cease; everyone knows that day will come. Therefore, this form of waste problem must be treated in the same manner as the solid waste problem or else the sludges and liquid must be transformed into the solid state. Some emphasis is being placed on the solid waste problem, such as the passage of the "Solid Waste Disposal Act of 1965". By this measure, governmental funds have been released for research in this area. But research is expensive and time consuming, and it is directed towards an ultimate solution which would undoubtedly result in exotic and sophisticated solutions which would in themselves also be costly and take considerable time to be implemented.

The mission of Industrial Services of America has been and will continue to be the implementation of systems, equipment and ideas to produce immediate partial solutions to the solid waste problem. The ultimate solution is years away.

It is important that rigid research and development works be emphasized and promoted to the greatest extent possible in the effort to find the ultimate solution to the solid waste problem. The more functional engineering approaches to the problem as outlined below should also be considered, keeping in mind that these are proven methods which are being used today to ease the problem.

History

Industrial Services of America implemented a research program a number of years ago to analyze the entire problem of solid waste generation, collection and disposal, and then went on to develop a systems-engineered solution that would eliminate present short-comings and still be economically feasible. It was felt that the systems approach to solid waste handling and disposal might disclose an economical method whereby industries and municipalities could better comply with sanitary waste disposal procedures prescribed by federal, state and local regulations.

Industrial Services of America research has resulted in an entirely new concept of refuse handling and disposal — a completely integrated, four-part (analytical, collection, processing and disposal) program — emphasizing analysis, proper equipment and technical knowledge for collection and disposal of industrial and commercial waste material.

Statement of the Problem

In this report the problem is divided into three parts:

A. Collection of waste at the source of generation and transportation to the processing plant.
B. Processing of the waste at the processing plant and transportation to the disposal area.
C. Ultimate disposition of the unreclaimed waste.

A. Collection of Waste at the Source of Generation and Transportation to the Processing Plant

Until some exotic means of intra-plant or inter-plant pick up of solid waste is universally adopted such as the "Solid Waste Pipeline" or some other method, the material handling problem is of the first magnitude and is increasing each day. The best way to cut down the number of trips of pick up vehicles, both inside and outside the plant, thereby reducing operating cost and decreasing the traffic problem, is to concentrate on proven methods which have been developed in recent years and which are becoming universally adopted.

1. Compaction

The concept of stationary compaction is not a breakthrough for the solid waste industry, but rather an extension of a trend. The commodity is waste, the means of transport is the truck or rail, and operation is on a full carload basis. Most people in the industry are familiar with the distinctions in freight rates applied by trucking companies and railroads to volume versus weight and are well aware of the fact that high density material is cheaper to ship than low density material. The difference in operating cost for a fully loaded vehicle is minimal compared to the partially loaded one. Basically the idea of stationary compaction is merely to take advantage of this very minimal differential and greatly increase the revenue per man-truck-hour. The greatest percentage of solid waste collection costs stem from the frequency with which material has to be removed from a location.

Therefore, implementation, wherever practical, of the compaction principle to reduce volume and maximize the payload per collection vehicle to its legal weight limit should be a requirement.

a. Starting at the refuse generation point, excess handling of refuse can be minimized by implementation of small, in-plant refuse carts. The carts, whether manufactured by Industrial Services of America's TRI-PAK Division or by the Plant's Engineering Group, should be rugged, easy to load and easy to push. In some applications, they should have the capability of being connected in trains, so they may deliver the refuse to the TRI-PAK stationary compactor in a more efficient manner. The compactor would have a dumping device so that these carts would be emptied automatically. A well-planned network of pick-up carts requires no refuse segregation and eliminates slow and costly extra handling. They not only speed and economize refuse collecting, but also improve plant housekeeping and safety. In addition, valuable plant floor space is usually made available.

b. The TRI-PAK stationary compactor squeezes the cost from the removal operation. All the plant refuse may be dumped into the compactor including pallets, skids, cardboard, garbage, and barrels. Here they are crushed to a fraction of their original volume. This refuse is thus forced into a reinforced compaction container which can be detached and removed at intervals. Compacted refuse means fewer trips to the processing plant with the best payload. Bigger payloads and few trips add up to a low cost per ton mile.

c. The TRI-PAK trailer and truck-mounted lift hoist are designed to efficiently pick up the filled compaction containers as well as open containers which would handle straight loads of metal or other dense objects. These units offer the best weight-to-payload ratio in the industry.

B. Processing of the Waste at the Plant and Transportation to the Disposal Area

Economics should definitely play an important part in the selection of a proper waste processing system. This may seem an anomaly since pollution control laws, corporate image or sense of social responsibility may precipitate a waste disposal program regardless of its cost. The cost conscious engineer and management should work toward the most economical and satisfactory solution to the problem.

It is easy to assume that incineration, deep-well disposal or other such methods are the most straight forward and, therefore, the most economical means of disposal. This approach may overlook the economic value of recovering components of the waste for reuse or sale through a reprocessing technique. The reprocessing system might cost five or ten times as much as the direct disposal of the waste, but the ultimate value of the recovered product might prove this approach to be the most economical solution.

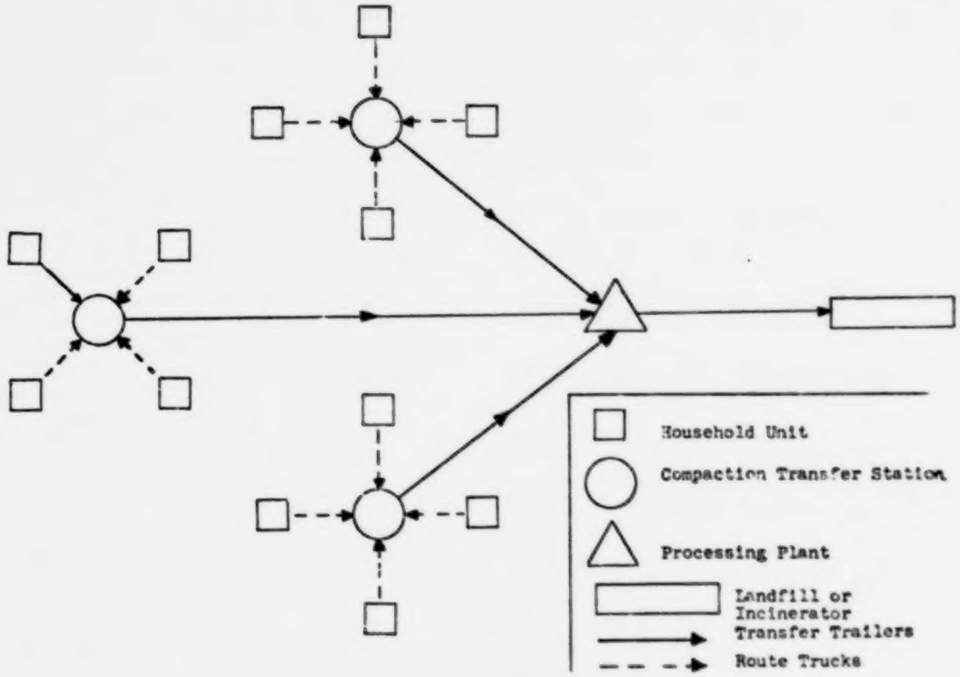

Figure 1: Household Waste Flow Chart #1

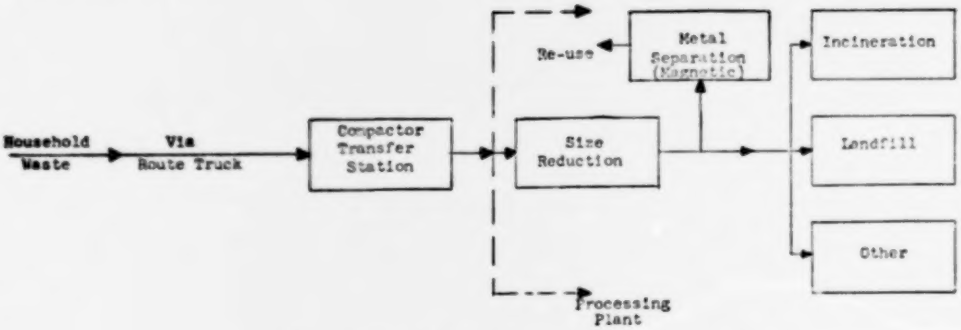

Figure 2: Household Waste Process Flow Chart #2

This does not mean that the value of the recovered material from the waste product will pay for the reprocessing system. This is seldom the case. It could, however, change the economics of the reprocessing system in contrast to direct disposal methods, so that the annual totals of the fixed and operating costs are less. This is true of wastes generated by large industrial plants where there is a large percentage of reclaimable cardboard, metals and wood.

This plant would inherently possess the qualities of a transfer station, in the respect that the smaller trucks or trucks with open containers which unload at the plant would not have to make the long haul to the disposal site.

C. Ultimate Disposition of the Unreclaimed Waste

It is universally conceded that heavy industrial waste, such as corrugated materials, wooden pallets, metals and sludges, do not readily lend themselves to our present ultimate, disposal methods. Therefore, they are working a hardship on our existing landfill and incinerator operations.

1. *Landfills*

A serious problem at landfills is the fact that insufficient fill compaction usually leaves a rather unstable ground condition. It is almost impossible to eliminate voids created by material that cannot be completely collapsed during initial compaction. By milling or pulverizing the material, these voids can be eliminated and higher compaction ratios can be realized. This extends the life of the landfill, sometimes as much as twice the normal expected life.[2]

This pulverized material thus provides a finished site that can be used almost immediately for new construction and foundation. Because of the inorganic nature of industrial-type refuse, many of the problems associated with household garbage, such as gas emissions, water pollution, etc., could be expected to be minimal.

2. *Incineration*

Incinerators all over the country are experiencing difficulties imposed by the heavy industrial wastes and many have refused to accept it. This type of material invariably causes higher maintenance problems at the incinerators, and the material has less favorable combustion characteristics than regular household refuse. In fact, most of the incinerators in operation today were designed for household type refuse.

The milling operation makes the industrial refuse very suitable for incineration, since the material is easier to convey and handle. It also gives the material greater surface area and thus better combustion. Several large European incinerator plants require reduction of industrial material.[3]

3. *Pyrolytic Decomposition of Solid Wastes*

Conversion of solid wastes into useful gases and charcoal by the pyrolytic process is still in its infancy. But even this method requires pre-sizing of the material.[4]

4. *Future High Temperature Incinerators*

Practically all of the designs for high temperature incinerators which are now on the drawing board require pre-sizing of the material. The high temper-

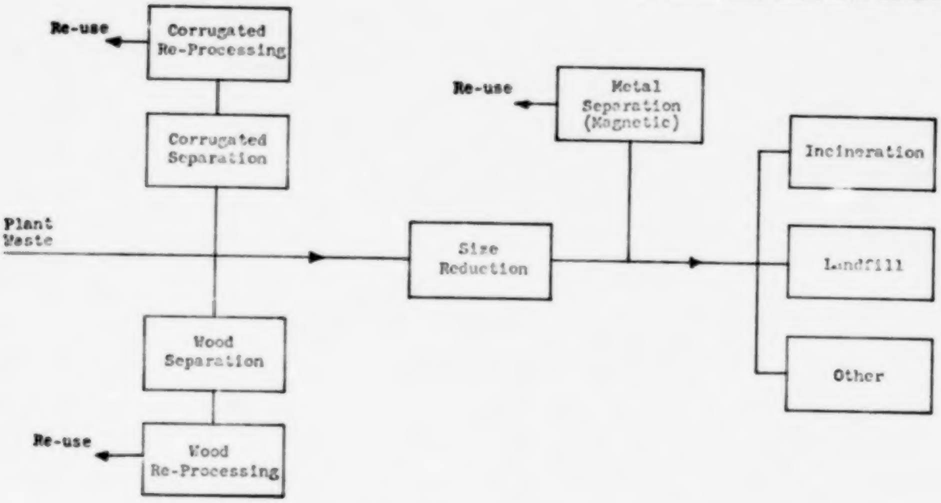

Figure 3: Plant Solid Waste Process Flow Chart

ature feature of these units should drastically reduce the air pollution problem inherent to the present day incinerator and leave only a small amount of residue.

5. *Bricking Operations*

High pressure "bricking" or baling operations for reuse as building material is being researched. Some of these processes require shredding of the material.

Other Processing Plant Utilization

It is entirely logical that the processing plant could be made available for use by surrounding towns or municipalities to ease their growing solid waste problems. This would definitely enhance the image of the industry or companies participating in the plant.

Although the only separation involved with household wastes would be the magnetic separation of the ferrous metals, the material would be put into an acceptable form for disposal.

By means of the hammermill, decomposition and fermentation is accelerated and the pulverized product does not attract vermin or insects. The build-up of heat in the mill, apart from the impact force of the machinery, destroys most flies, eggs, and larvae brought in with the refuse. Rapid consolidation of the material increases the exclusion of oxygen at the fill, thus reducing the risk of spontaneous combustion. Another benefit is the swift settling of the layers which would allow vehicles to ride on it without difficulty.

A Look to the Future

The constantly increasing imposition of governmental restrictions indicate that both communities and private industry must make basic changes in their present practices and spend vastly greater sums of money for compliance. Industrial Services of America feels that it has an acceptable program that will reduce this industrial and civic economic burden, since hauling and labor costs are bound to increase.

Demand for recycled materials can only increase. Americans are coming to realize, however, that a reckless cutting down of timber to supply packaging is too costly in many ways. Cardboard, metal and wood must be reworked and used over and over again. Otherwise, nature will take its inexorable toll, its irreversible toll, and this may be more than we can pay and still survive.

REFERENCES

1. "Solid Waste Pipeline", Iraj Zandi, Towne School of Civil and Mechanical Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.
2. "Pulverization at British Site Reduces Matter by 50 Per Cent," Solid Wastes Management Magazine, pg. 16, February 1968.
3. Amsterdam Municipal Incinerator
4. Public Works Magazine, pg. 82, August 1968.

A Thermodynamics and Physical Properties Package (TAP)

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A computational package for thermodynamic and physical properties is basic to any computer-aided chemical design system.

In general, a physical property package can be used on a stand-alone basis, or it can be core-loaded along with the main design package. CHESS and CHEOPS are examples of systems where some generalized property calculation capability is incorporated into the main package. PACER and CHIPS are examples of systems which use stand-alone property packages. There are advantages and disadvantages to both approaches.

TAP was designed as a stand-alone package. It is currently being modified for inclusion into CHESS, and a commercial time-sharing version has been written.

The system presented was developed with the intention of providing the engineer with the tools required for the calculation of physical properties with a computer. The system can calculate properties for pure components as well as for mixtures. It was designed to be expanded or modified to accommodate changes in the field of physical property estimation. TAP was developed to allow the user, if he so desires, to choose his own method of computation within the capabilities of the system.

General Description of the System

The package is written in FORTRAN IV-H and consists of about 3,200 FORTRAN statements (including comment statements). The total memory space used is 11K. In cases where just a few of the subroutines are required, the entire package need not be used. The superfluous subroutines can be removed, substituting each one by the first and the last cards (to avoid error messages). In this way, the size of the package can be reduced considerably.

TAP consists of a main subroutine (ROADMP) which calls any of the 41 subroutines listed in Table 1. How these subroutines are called depends on the route and the information available to the system. ROADMP has the capability of choosing the most convenient way of calculating a given property. It searches one by one through the arguments required by the subroutine in question. It locates missing arguments, and then calls other subroutines to estimate these arguments. The engineer can use as much experimental data as he wishes in the calculation of any property. As a rule of thumb, it can be said that the fewer subroutines required, the better the results obtained.

In the development of the package, each subroutine was checked separately with experi-

TABLE 1
Listing of Subroutines

Name	*Number (ISUB)*	*Description*	*References*
AFE	20	Accentric Factor by the method of Edmister.	25,26, 6
ZRW	11	Compressibility factor, fugacity coefficient and volume of a gas by the equation of Redlich-Kwong.	31
ZRWM	8	Compressibility factor, volume and fugacity Coefficient of a mixture of gases by the Redlich-Kwong equation.	31
ZCGBM	6	Critical compressibility factor by the method of Garcia Barcena.	7
CVD	9	Critical volume by definition.	
LDYWM	13	Satured liquids densities by the method of Yen and Woods.	29
CLDYWM	15	Density of compressed liquids by the method of Yen and Woods.	29
DCSB	5	Diffusion coefficients for binary dilute gas mixtures at low pressures by the method of Slattery and Bird.	14
DDSOT	18	Diffusivity coefficients for dilute aqueous solutions at low pressures by the method of Othmer and Thakar.	15
DDNASS	17	Diffusivity coefficients for dilute non-aqueous solutions at low pressures by the method of Scheibel.	16
IGE	1	Enthalpy from the heat capacity equations.	
EGM	26	Isothermal enthalpy deviation (effect of pressure and composition) for a mixture of gases using the Redlich-Kwong equation.	32, 33
SLE	21	Enthalpy of saturated liquids above the ideal gas enthalpy at the same temperature by the correlation of Erbar, Persyn and Edmister.	33, 34
SLEM	31	Enthalpy of saturated liquid mixtures above the ideal gas enthalpy of the mixture at the same temperature by the correlation of Erbar, Persyn and Edmister.	33, 34
EPGRW	23	Enthalpy and Entropy of a pure gas at any temperature and pressure by the Redlich-Kwong equation.	32,33
ESLYA	25	Enthalpy for pure subcooled liquids by the method of Yen and Alexander.	35
SLEYA	24	Enthalpy for pure saturated liquids by the method of Yen and Alexander.	
ENTIG	22	Entropy from the heat capacity equation.	
DHVBG	4	Heat and entropy of vaporization at the normal boiling point by the method of Giacalone.	27
DHVWM	3	Heat and entropy of vaporization at any temperature by the method of Watson.	28
IGHC	2	Heat capacity as a function of temperature.	
MIXRUL	30	Mixture rules by Kay's method.	
LTCRK	16	Thermal conductivity of organic liquids by the method of Robbins and Kingrea.	21
TCGLP	28	Thermal conductivity of a gas at low pressures by the method of Misic and Thodos.	
TCGHP	29	Thermal conductivity of a gas at high pressures by the method of Stiel and Thodos.	17, 18
GMTCLP	34	Thermal conductivity of gas mixture at low pressures by the method of Lindsay and Bromley.	20
GMTCHP	35	Thermal conductivity of a gas mixture at high pressures by the method of Stiel and Thodos.	19
TCBML	36	Thermal conductivity of binary liquid mixtures by the method of Filippov.	22, 23
VAPRE	7	Vapor pressure at any temperature by the correlation of Riedel, Plant and Miller.	24
VLBBP	32	Viscosity for liquids at temperatures below the normal boiling point using the equation: VL = A*EXP(B/T).	
LQMV	33	Viscosity for liquid mixtures by the mixture rules of Arrhenius.	6
GMLPV	12	Viscosity of gas mixtures at low pressures by the method of Wilke.	12
VGMHP	14	Viscosity of nonpolar gas mixtures at high pressures by the method of Dean and Stiel.	13
VSTM	10	Viscosity for gases at low pressures by the method of Stiel and Thodos.	8, 9
VJSTME	19	Viscosity for gases at elevated pressures and for liquids at temperatures above the normal boiling point by the method of Jossi, Stiel and Thodos.	11
LMV	27	Volume of liquid mixtures at any temperature and pressure by the method of Yen and Woods.	29
IFTB	37	Enthalpy of formation from Parachor.	36, 37
ENTPF	38	Entropy of formation from Parachor.	38
HRX	39	Heat of reaction by definition.	
FFTG	40	Free energy of formation from Parachor.	39
FERXN	41	Free energy of reaction by definition.	

mental data. In this way it was possible to verify the programming of the correlations, and to establish the error bounds which are included as comment cards with each routine. A test program which calculates the error for each subroutine is included in the tape furnished to the user. If the limits of applicability of a correlation are exceeded, warning messages are printed.

For all subroutines, the input data are used directly as subroutine arguments. Each subroutine returns only one parameter to the main program (this is labeled ANSW). Other parameters, if desired, can be taken from COMMON.

The TAP program does not generate vapor-liquid equilibrium data; however, a companion program KVALUE, does (40). Algorithms have been written that combine the subroutines required to produce complete thermodynamic charts.

Expansion of the System

The package can be expanded or modified easily. When one of the correlations becomes obsolete, the old subroutine can be replaced, providing the same common statements and calling arguments are maintained. If the improved method requires additional arguments, they can be added at the end of the appropriate COMMON statement.

To expand the system a few statements must be written in the same fashion as the ones already there. Also at the beginning of ROADMP, the statement that says: GO TO (1,2,3 . . . 41) ISUB, must be modified by adding the new label statement to the list. Suppose that the subroutine that is going to incorporate this statement has 3 input arguments: NEWSUB (ARG1,ARG2,ARG3,ANSW). In this case, the modifications to ROADMP might be:

At the beginning:

```
   GO TO (1,2,3,4,. . . .,41,43)ISUB
```

At the end:

```
   42 IF(ARG1.LT.0.0001) CALL YY (X,X,X, . . .)
      IF(ARG2.LT.0.0001) CALL YYY (Z,Z,Z, . . .)
      IF(ARG3.LT.0.0001) CALL YYYY (W,W,W, . .)
      CALL NEWSUB(ARG1,ARG2,ARG3,ANSW)
      ARG1=0.0
      ARG2=0.0
      ARG3=0.0
      RETURN
```

Statements 1, 2, 3, 5, 6, 7 are necessary only if ARG1, ARG2, or ARG3 are to be calculated from other subroutines (YY, YYY, YYYY, in this case).

The correlations for mixtures currently accommodate up to 20 components. If there are more components, an adjustment can be made in the appropriate COMMON statements.

Other Physical Property Packages

The most publicized of the available systems is the AIChE Physical Properties Package.[1 2 3] This consists of 40,000 FORTRAN statements which occupy about 32K of memory. Originally written in FORTRAN for an IBM 7090/7094 computer, it has been translated into FORTRAN IV at the Gulf Research and Development Company. The system is large and expensive; one company reported that it required a one-man-year effort to make the system operable. The size and complexity are due to the subroutines which seek out minimum error paths for each computation. All major users have, to the best of the authors knowledge, abandoned this portion of the programs and have simply cannibalized the subroutines (41).

Other packages which have been reported in the literature include those of Phillips and ESSO.[4 5]

Physical and Thermodynamic Property Correlations Used

A balance between the following factors is considered basic in the selection of a correlation:

1. Agreement with the experimental values.
2. Limits of applicability.
3. Type and amount of data required.
4. Speed of computation.
5. Memory required.

```
LDYWM     13    TC,ZC,VC,T
                TC,ZC,T,PC
                TC,T,VC,TBP,AM,L
                TC,T,TBP,AM,L,PC
```

Figure 1: Route Selection for LDYWM

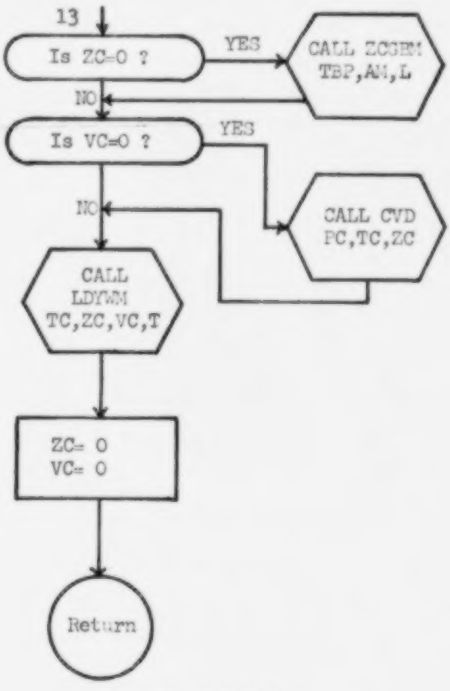

Figure 2: ROADMP Logic

```
                                                                   STATEMENT
                                                                    NUMBER

    COMMON/PRO1/ PC,TC,ZC,VC,AM,TBP,A(10),TR,A2,B,TT1,TT2,W,T1,T2,       1
   1UE1,UE2,AK1, AK2,AW1,AW2                                             2
    COMMON/PRO3/ T,P                                                     3
    COMMON/FLAG1/NJ,L,NCP,NCOE,N,K,I,II,KA,NN,IH,IGAS,IMH,IKF,IXY,       4
   1NPOLAR                                                               5
    DIMENSION ANAME(5)                                                   6
 1  FORMAT(5A4)                                                          7
 2  FORMAT(6F10.2,2I2)                                                   8
 3  FORMAT(20X,5A4,2F10.2,F10.3)                                         9
 4  READ(5,1,END=6) ANAME                                               10
    READ(5,2) TC,PC,T,P,TBP,AM,L,ISUB                                   11
    CALL ROADMP (ISUB,ANSW)                                             12
    WRITE(6,3) ANAME, T, P, ANSW                                        13
    GO TO 4                                                             14
 6  STOP                                                                15
    END                                                                 16
```

Figure 3: A Main Calling Program

As a general policy the AIChE recommendations were followed unless more recent and improved correlations were available. In essence, this program, like the AIChE program, is a computerized version of Reid and Sherwood.[6]

The Main Subroutine — ROADMP

ROADMP currently contains most of the information normally found in a user's manual. This includes a listing of subroutines, returns, nomenclature, instructions for use, the roads and a sample problem.

Figure 1 shows a sample of one of the simplest ROADMP route selection entries. Subroutine (ISUB) number 13, LDYWM (liquid density by Yen-Woods method) can be reached using any of the four sets of input arguments listed. The roads are given in decreasing order of priority; thus the preferred way of getting liquid densities is to furnish critical temperature (TC), critical compressibility (ZC) and critical volume (VC) as input parameters.

Figure 2 is a section of the ROADMP flow sheet which illustrates the logic pattern. If ZC is not provided, it is calculated by ZCGBM, in which case the boiling point temperature, TBP, the molecular weight, AM and the flag L must be provided. If the critical volume is not furnished it is calculated by CVD, providing the critical pressure (PC) is furnished. The calculated parameters must be set equal to zero so that ROADMP will not use these values in the next computation.

For many of the properties, as many as twenty or thirty different paths exist. In general, only those paths which have some basis in reality were programmed.

Main Calling Program

A sample main calling program is shown in Figure 3, which would calculate the enthalpy of subcooled liquids ANAME (1), ANAME (2)... ANAME (5) at temperature T. The subroutine is ESLYA (ISUB 25).

Statements 1-5 are the common statements required by ISUB 25. Statements 5-8 are the FORMAT input-output statements; the input data is specified in 9 and 10. Of the arguments required by ISUB 25 listed in Table 25, (ZC, TC, PC, T, P), ZC is assumed to be unavailable. However, upon consulting ROADMP it was found that the parameters TBP, AM, and the FLAG L can be used in place of ZC. (Subroutine ZCGBM is automatically called by ROADMP). Statement 12 tells roadmap to proceed with the calculation. The enthalpy of the subcooled liquid is returned as ANSW.

Program Availability

TAP is available at the University of Houston in the form of nine track, 800 bits/in. tapes, and we will be pleased to furnish copies to University and research groups at cost. Commercial distribution and time-sharing systems are handled by ChemShare Limited, Box 2310, Norman, Oklahoma 73067.

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Developing Thermal Energy Release Intensity Parameters for Solid Wastes

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BACKGROUND

For many years the community-at-large has been taking for granted industry's relentless effort and search for by-product potential in the wastes of production and consumption. However, the accelerating generation of wastes about which one reads daily, hears, or sees daily and the increasing awareness and sensitivity to the despoiling of the environment has created greater urgency and emphasis to the need for effective conversion of wastes for useful purposes or at least into inoffensive form.

The highly competitive marketplace and associated price/tax squeeze on profits are providing ever greater impetus to minimize production wastes and to search those wastes that still occur for latent benefit, and to avoid the increasing costs of disposal.

When virtually all avenues of practical in-plant recycling of wastes have been exhausted, and whether or not there is a potential purchaser of the remaining waste, prudent management usually explores its fuel value potential to establish the most economic disposition.

Since fuel cost is usually a significant and continuous operating expense for most industrial enterprises, this search has many times focused on waste as a possible beneficial fuel. Recovering the thermal energy in production wastes (i.e., solids, liquids, or gases) has been receiving increasing consideration. Usually waste fuel combustion is supplemented by one of the commercial fossil fuels to satisfy the total energy requirement and/or to control more accurately the combustion process for maintaining equilibrium conditions.

Other attractions for in-plant waste conversion are that they eliminate the cost and dependence on others for disposal, as well as maintain confidentiality of the process and its residues.

If the waste quantity and its fuel value are significant and the thermal energy can be reliably released and controlled, capital expenditure for the energy conversion system may be justified. The chemical, toxic, corrosive, infectious or possibly hazardous potential of the waste might actually dictate on-site disposition.

For some indication of the fuel value and combustion characteristics of solid wastes, the traditional proximate and ultimate analysis is made, usually using the ASTM procedures developed for coal and coke. The expectation is that parallels might be drawn from the vast library of analysis information and the related burning characteristics accumulated through the years for the broad cross section of coals.

Proximate Analysis

Although the proximate analysis data and the determination test procedure is fundamentally empirical, it does provide an insight into the burning character or burnability of the solid fuel. This insight is obtained by relating the proximate analysis data to the actually burning characteristics experienced in furnace systems. This has been done extensively for coal.

There is some variation in the chemical make up of all fossil fuels, but the variation in the chemical and physical character of coal is quite broad. Discrete chemical ultimate analysis alone will provide the elements to determine theoretical requirements (heat and mass balances) for combustion, but will not reveal burning characteristics such as the rate of energy release, tendency to form soot which is so difficult to burn, when and at what temperature the reaction becomes exothermic, etc. . . .

As mentioned, there is a broad variation in coal quality, with variations existing not only in different sections of the country, but within coal regions, and even coal seams. However, these variations may be considered narrow when compared to what might be found in the spectrum of industrial solid wastes.

Yet even within the narrower spectrum of coal characteristics there are many occasions when the actual burning performance experienced does not correspond to what was anticipated based principally on the usual proximate analysis data. Therefore, when burning waste materials it should not be startling to discover a marked difference in actual performance from that which might have been anticipated based on this type of analysis data.

There is need to expand upon and refine the indicators provided by the proximate analysis to better reveal the probable burning characteristics of the fuel and thereby facilitate more suitable furnace designs.

The proximate analysis provides data on moisture, volatile matter, fixed carbon (by difference) and ash as well as calorific value. The sulfur constituent is also usually reported but is determined separately. The "combustible" is considered to be made up of volatile matter and fixed carbon. The volatile fraction is determined and the fixed carbon fraction is then the difference.

Volatile matter is not really a discrete entity, although use of the term implies that it is as absolute as the calorific value. Simply stated, volatile matter is considered to be the combustible gaseous products which evolve when a solid fuel is heated within specific constraints of time and temperature. These distilled pyrogenic gaseous products are "principally" a mixture of complex hydrocarbons. These gases usually have a relatively low ignition temperature and when intimately mixed with oxygen, ignite readily and burn rapidly.

The vigorously burning volatile matter accelerates, and helps maintain ignition of fixed carbon fraction of the "combustible" in the remaining solid fuel. Fixed carbon has a relatively high ignition temperature, is usually more difficult to provide with sufficient oxygen, and, therefore, burns more slowly, producing a less stable flame.

Everyone has heard many times of the 3T axiom, that complete combustion requires ample retention time, in the high temperature region, and with renewing supplies of oxygen. The enigma lies in the fact that for some fuels, particularly some waste fuels, a few seconds may be ample time and yet for others 40 - 60 minutes might not be enough. Similarly, some waste fuels may require temperatures less than 1400°F while others would require more than 2400°F for expeditious combustion.

In general, solid fuels with higher volatile fractions usually have higher rates of energy release. However, the furnace environment, fuel sizing, or even other fuel characteristics such as high moisture or high ash or both may act as a depressant on the energy release potential.

For effective utilization of purchased fuel and especially for industrial solid wastes which are to be burned, it would be desirable to know as much as possible about these two fractions of their "combustible."

For many industrial wastes even the volatile matter quantity, as traditionally determined, reported and related to past burning experience, has too many times been an inadequate indication of what will actually occur in the furnace environment. However, some scale burning trials do help in attempting to find adequate indices for design and operation.

Volatile Matter Determination

The current method of volatile matter determination, described briefly, requires that a 1 gram air-dried fuel sample, ground to pass a No. 60 sieve, be placed into a weighed 10 ml platinum crucible equipped with a close fitting cover. The crucible and contents are then heated in the laboratory electric furnace to 950°C (±20°C), approximately 1750°F, and maintained for exactly seven minutes. The crucible is then removed and without disturbing the cover, allowed to cool and is then weighed. The loss in weight minus the moisture weight loss, which was determined previously by oven-drying (105°C for one hour) is considered the Volatile Matter fraction of the combustible.

When different solid fuels have their volatile matter determined in this prescribed manner, analysis comparison of one fuel with another can be meaningful. This is particularly significant when their burning characteristics are also assessed in an actual furnace, enabling some correlations to be made, which may generally be used for performance predictions.

Solid waste fuel characteristics cover a much broader range than the usual commercial fuels, and it is apparent we are in need of a method or procedure which would provide information more descriptive of the energy release phenomena than currently made available.

There has been some discussion regarding this need and the possible approach to meet it. It has been suggested that a procedure might be established which would provide this information in an elapsed time framework and at several practical and appropriate temperature levels. This would provide a broad reference base when compared to now having but *one value*, which is arrived at after a specified time (7 minutes) at a specific (950°C) temperature, Point P, Figure 1.

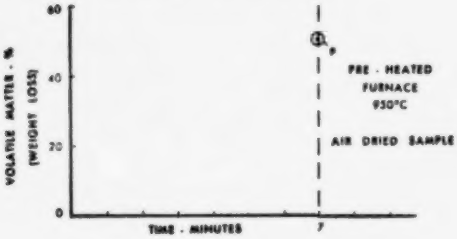

Figure 1

Meaningful guidance might be provided in even knowing whether the volatile was released at a uniform rate during the prescribed holding time, such as Curve B, Figure 2, or whether much of the volatile release was during the early period, perhaps as Curve A, or toward the end of the holding period, perhaps as Curve D. The nature of the material may even result in some sort of staged volatile release, such as Curve C.

For each discrete waste (by-product) fuel, characteristic information to be generated might appear as a family of curves with volatile energy release (weight loss) as the ordinate and the elapsed holding time as the abscissa.

Each curve would be at a particular temperature level, e.g., 950°C, 550°C, 300°C. These curves would reveal the *rate* of volatile energy release and the *total* volatile energy release with time lapse at each of the temperature levels selected, (hypothetically Figure 3).

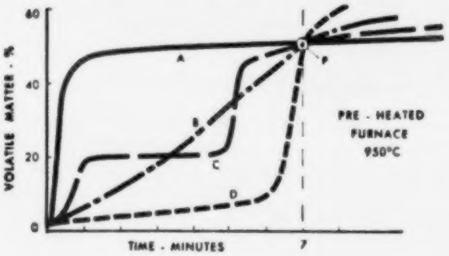

Figure 2

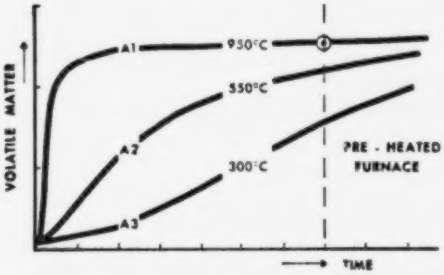

Figure 3

Another possibility, and perhaps in addition, is the development of a similar family of curves but oriented to reveal the effect of *different rates of heating* on the fuel devolatization or energy release.

Perhaps adaptation or modification of derivative/differential thermogravimetric analysis equipment and/or techniques would also provide a simultaneous plot indicating at what temperatures and time autogenic ignition (combustion) ensues, or whether it takes place at all. This information would indicate the need and perhaps even the extent of supplementary fuel requirements.

Graphic fuel characteristic information systems are needed to provide better parameters for furnace design. The influence is not only on furnace configuration and size, but will better guide the determination of the need for and selection of:

- —size, shape and location of arches
- —size, number, and locations of overfire air jet systems—staggered, interlaced rows—or in tangential con-current/contra-current belts

- sizing, locations and types of auxiliary/supplementary burners
- extent and locations of furnace wall/roof cooling
- ratios of primary, secondary and tertiary air
- others

Relevance to Furnace Design

There has been a significant number of furnace systems designed to accommodate particular waste fuels based on indices using the traditional proximate analysis some with and some without actual burning trials. Although many of these furnace systems had been considered adequate at the time, they may not be adequate in today's view. In the past, there have been some furnaces which were obviously inadequate to cope with the projected task, basically as a consequence of insufficient awareness of the actual energy release characteristics of the waste.

Circumstances such as these prompt the common reference that even with today's technology, design and operation of solid fuel burning systems is still more an art than a science.

At a recent presentation by Adel F. Sarofin, Associate Professor, MIT, at an ASME Incinerator Division Symposium he brought out that the processes involved are so complex that designers have had to rely on experience and empirical relations rather than on attempts at quantitative description of the chemical kinetics and heat, mass and momentum transfer relationships.

There is a need for viable indices which can be referred to and readily applied to practical real situations.

Recognizing this urgent need for such graphic fuel characteristic information systems and anticipating their significant beneficial impact on the parameters for furnace design, exhaust gas quality control and systems operation, our combustion laboratory and research and development division have already initiated feasibility investigations.

Although the fundamental element for a successful industrial solid waste thermal recovery system is full awareness and appreciation of the combustion characteristics of the waste fuel, the following aspects and considerations also strongly influence the adequacy of the system:

- material handling system
- fuel size reduction requirements
- surge storage and reclaim provisions
- furnace fuel feed mechanisms
- furnace fuel feed metering system
- furnace configuration, size, and materials of construction
- combustion air systems
- instrumentation, recorders and process controls
- provisions for furnace system cleaning
- exhaust gas quality control system
- residue characteristics and handling system
- wastewater discharge quality control

The intent of this discussion was to focus attention on the import for developing a comprehensive approach to provide more meaningful information regarding the intensity of heat energy release in an elapsed time framework for solid waste materials. In conclusion, this is but one of the areas that must be probed further to provide practical application parameters for furnace system designs — obviously, there is much work yet to be done.

Open Pit Incineration of Industrial Solid Wastes

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Thermal Research and Development Corp.

This paper discusses a development for the incineration of industrial solid wastes. In order to discuss the open pit incinerator, a brief synopsis of the background of the incinerator will help to fully understand the work that has been done for the past several years.

In 1965, E. I. DuPont De Nemours & Co. sought a method to dispose of off specification of nitrocellulose. For many years this waste was merely spread over a rather large area and ignited to burn with resulting air pollution. This method of burning has long been discussed and is not part of this discussion.

Mr. E. S. Monroe, Jr. Senior Consultant, E. I. DuPont De Nemours & Co., developed a theory whereby the scrap nitro-cellulose would be charged to a unique incinerator and burned with smokeless combustion. Because of the high flame temperature that would result from this combustion, the incinerator design must have a feature where the heat is rapidly dispersed without resulting damage to the refractory lining. The conclusion was reached that one of the most effective ways of accomplishing this would be to have the heat radiate to atmosphere. In order to overcome the problem of open burning, controlled combustion air must be provided.

After much investigation it was concluded that a rectangular type of incinerator with an open top would be the ideal solution to the problem. In order to have controlled combustion air, a forced draft fan would be provided and air enter the incinerator through air manifold with a series of nozzles directed into the incinerator at the proper velocity and quantity to achieve smokeless combustion.

The first of the open pit incinerators was installed at the DuPont Company's Carney Point plant in New Jersey. It proved to be extremely successful in the combustion of scrap nitrocellulose. As a natural course of events it was immediately recognized that this type of incineration system could not only handle high heat release materials such as nitro-cellulose but many forms of solid waste materials. Acting on this theory other solid waste materials were tried and burned successfully in the pit incinerator. At approximately this time, Thermal Research & Engineering Corporation was invited to watch a demonstration of the open pit incinerator. Subsequent to this, it was immediately recognized that this type of incineration not only held promise for the waste materials that were being burned but properly developed, the system could be used for a wide range of solid waste materials. At this point, the development of the open pit incinerator was in its infancy. Much work would have to be done to develop it to the point where it could handle different wastes and achieve good combustion characteristics and meet air pollution requirements. Much of the early development work done by duPont proved to be invaluable and any of the parameters as originally established are still valid today.

The initial work that was done indicated that the optimum width for the unit would be between 8 and 9 feet. With the air velocities that were developed through the air manifold and nozzle assembly it was established that this width provided the optimum operating conditions with minimum fly ash and good combustion characteristics. Since not all of the combustion air actually entered into the combustion reaction, it was theorized and later proven through actual experience that a large quantity of excess air would have to be provided to the incinerator. After much experimentation, the combustion air blower was optimized at 100% excess air for the theoretical heat release in the unit.

This led to the establishment of certain combustion air requirements per foot of hearth length. The development work carried on by our company and DuPont established that 850 SCFM of combustion air were required per foot length of incinerator for waste materials having a heating value of 10,000 BTU/lb or less. The required pressure of air was established at 11" of water column.

For higher heating value materials for instance, scrap, polyethylene, polypropylene and other plastic wastes which generally range up to 20,000 BTU/lb, the combustion air requirements would be on the order of 1100 SCFM and at a pressure of 16"of water column. The higher pressures were dictated by higher flame speeds of the scrap material and consequently it was required to have higher air velocities to achieve good combustion characteristics.

Further investigation, which incidentally is still being conducted, has established a wide range of operating conditions for the pit incinerator. Investigations have shown that not only quantity and pressure of combustion air being varied for the particular type of wastes being burned but also other criteria regarding the operation of the open pit incinerator.

For instance, operating procedures had to be established for different types of solid wastes. In an early installation made at a chemical company in Texas, the incinerator was installed to burn scrap polyethylene. At this time, which was several years ago, little was known on how to handle polyethylene in the pit incinerator. When first installed, the unit was merely charged with a quantity of polyethylene and ignited. The resulting smoke resulting from the first trial was probably worse than open burning. It was quickly learned that the quantity of polyethylene charged to the unit and the interval of time between charges would have to be programmed on a regular procedure. Upon investigation it was found that the optimum charge would have to be approximately 400 lbs and the unit would have to be loaded every 6 to 7 minutes. This provided excellent combustion characteristics and smokeless combustion.

Soon after this installation was made further work was done to expand the range of materials being handled in the incinerator. Market studies were made and it was learned that small communities with a population up to 15,000 people could not afford expensive incinerators for municipal trash and garbage. We therefore embarked on a program to install several units in the small communities. Our first installation was made in the town of Ajax in Ontario, Canada. Ajax is a town with a population of approximately 10,000 people but also has several industrial plants that would contribute their solid wastes to the pit incinerator. Adding this waste to the system, the unit is handling the waste comparable to a town of 15,000 people.

The Ontario Pollution Control Authorities were consulted and approval was obtained to make the installation. In this system, all types of solid wastes including both municipal and industrial wastes are being burned in the unit. From theoretical calculations, the system was designed to handle a capacity of approximately 5,000 lbs/hr of mixed solid wastes. Initial parameters took into consideration lost time and a certain amount of conservatism for the rating. Since the installation of the unit and with familiarity gained through experience, the incinerator has been disposing approximately 3 to 4 tons per hour of solid wastes.

Thermal Research & Engineering Corporation has furnished 20 of these open pit incinerators. The duPont Company has approximately 25 in service and there are at least 20 other units which by and large have been designed and built by companies for their own use. Therefore, at least 65 open pit incinerators in operation prove that this type of incineration system is not in the experimental stage but has proven experience and has gained wide popularity.

Applications of the incinerator not only has been used for general trash and other waste materials as discussed previously, but also includes units for general refinery type wastes including sludges, nylon scrap and even the disposable diaper as made by some companies.

Several companies have designed and built the open pit incinerator for liquid burning and with several modifications it can be successfully used for liquid disposal.

This is not to say that the open pit incinerator is a panacea for all types of waste disposal. It does have its limitations and cannot be used for universal solid waste disposal. For instance, the incinerator cannot be used for solid wastes that contain chlorine or other halogens. When burning these types of wastes, hydrochloric acid or other halogenated acids are formed. Not only would this cause air pollution but would be a menance to health. Another type of waste that cannot be handled in the incinerator is polystyrene. There are technical reasons why polystyrene cannot be burned successfully but suffice it to say that this type of burning produces heavy dense smoke.

Figure 1 shows the installation of the incinerator from the rear of the incinerator. On the left hand side is the combustion air fan providing the combustion air for the incinerator. The screen at the top of the incinerator is to prevent fly ash from entering the atmosphere. On the lower section of the figure, in the solid section is a windbreak to prevent atmospheric winds from interfering with the combustion process.

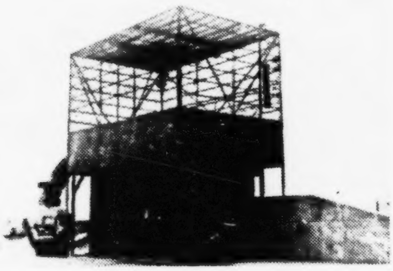

Figure 1

Figure 2 shows the incinerator from the loading end with the loading door in the open position.

Figure 3 shows a typical method of charging the incinerator. In this instance, a front end loader is being used to charge solid waste to the unit. Other methods can and are being used. This includes direct dumping from a dump truck or from a Dempster Dumpster.

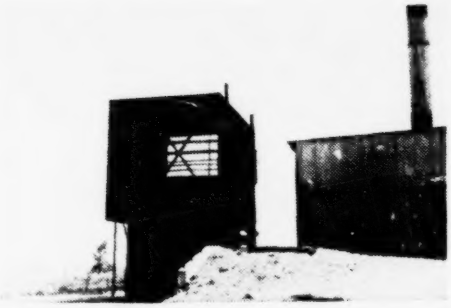

Figure 2

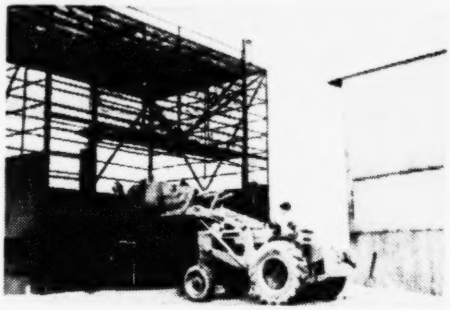

Figure 3

The simplicity of the pit incinerator is illustrated in Figure 4. An operator is shown igniting the unit. He merely takes a small bag, lights it with a match or a cigarette lighter, and drops it into the unit which has been precharged with a load of waste. Upon initial ignition the combustion air fan is raised to the proper operating level where combustion then proceeds rapidly.

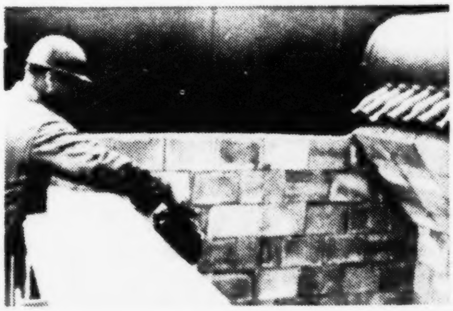

Figure 4

It is important to bear in mind that on initial start-up there will be some smoke but after a short period of time, smokeless combustion will be achieved with proper operation. Figure 5 shows a load of solid waste that is almost completely burned. All that remains are the noncombustibles which will be removed in the form of ash.

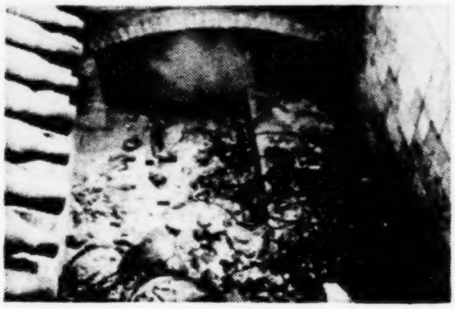

Figure 5

Figure 6 shows a typical method of removing the ash. The same front end loader that was used to charge the unit is now being fitted with a clean out tool. The tool is several feet longer than the length of the hearth of the incinerator so that upon raising both clean out doors, the clean out tool can be pushed from one side of the incinerator completely through to the other removing all of the ash. Figure 7 shows the tool being fitted into the bucket of the front end loader.

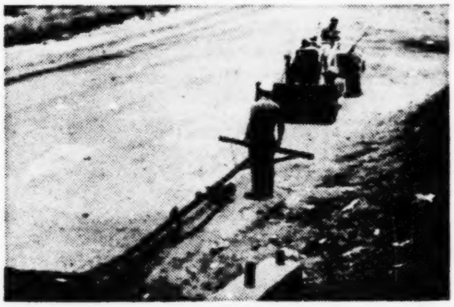

Figure 6

The clean out tool in a position to enter the incinerator is shown in Figure 8. Note that a modification has been made to the bucket so that the tool can be raised and lowered merely be raising and lowering the bucket.

Figure 9 shows the ashes being pushed from one end of the incinerator through the other end and this was taken from the top of the incinerator. Since the clean out doors are somewhat smaller than the hearth width, several passes must be made but complete clean out can be made within a period of 15 minutes. Here it is important to remember that if the depth of ashes are too deep, then it will become increasingly difficult to properly clean the unit. The next figure (Figure 10) shows the incinerator being cleaned out with the clean out tool completely through the incinerator and looking from one end

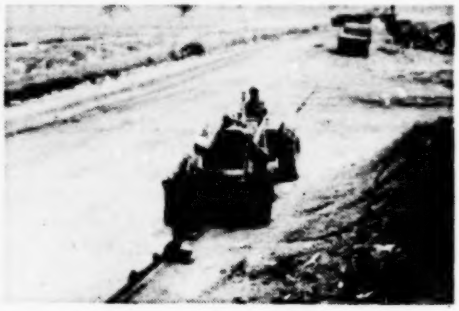

Figure 7

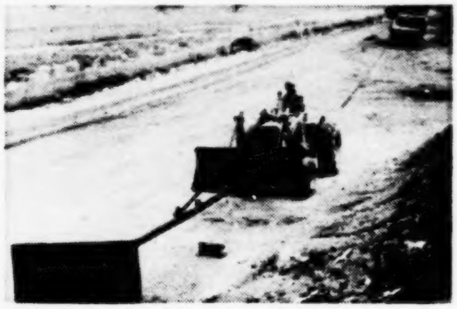

Figure 8

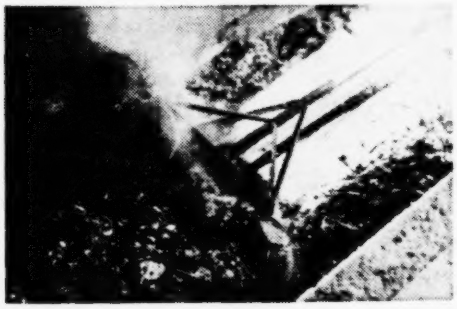

Figure 9

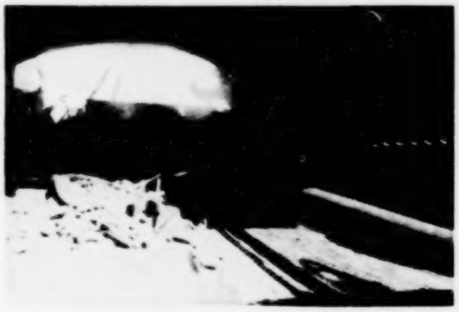

Figure 10

through to the other end.

These figures represent a complete cycle of the incinerator starting with charging, ignition, burning, and clean out.

Thermal Research & Engineering Corporation, in cooperation with an independent testing laboratory has conducted emission tests on a pilot scale unit. Isokinetic samples were taken at five different points. Four of these were at the top of the screen enclosure and one at the top of the incinerator near the loading point. Three different types of wastes were tested. These included polypropylene, general trash and municipal garbage.

Test results showed particulate emissions of:

1. 0.017 grains/ft^3 for polypropylene
2. 0.005 grains/ft^3 for general trash
3. 0.047 grains/ft^3 for municipal garbage.

The Office of Solid Wastes Disposal will conduct further testing on a municipal incinerator in the future. The program to be conducted will include tests for particulates, hydrocarbons, carbon monoxide and oxides of nitrogen.

It is best to remember that for proper operation and optimum combustion, the incinerator should be charged at a fairly constant rate to maintain as even a combustion rate as possible. This not only heats the refractory which re-radiates heat into the incinerator, but also maintains good combustion characteristics with minimum amounts of fly ash and unburned combustibles being discharged to the atmosphere.

It is well to remember that the open pit incinerator is a useful and proven tool for the disposal of solid wastes. While it is not a panacea, it can be used effectively in many different types of waste disposal problems where other methods are either uneconomical or impractical. Properly operated, the open pit incinerators can dispose of solid wastes to meet air pollution codes, for a wide range of solid wastes.

Incineration of Non-Aqueous Liquid Industrial Solid Wastes

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INTRODUCTION

Perhaps the incineration of non-aqueous liquid industrial solid wastes is only "a small atom among large molecules," but its potential energy is significant. To many a manufacturing process in an ever increasing sophistication, it offers an important relief valve for disposal of by-products in the process.

The term "Liquid industrial solid wastes" may seem anomalous. Yet all of the three states of matter — gaseous, liquid and solid — are involved in each of air, water and solid waste technology. Non-aqueous liquid wastes are subject logically to solid waste treatment. In treating this subject we shall review prior art but even more we shall attempt to set forth a frame-work for organizing and building on the meager related science.

Classification

Before reviewing the history and technology, consider the nature of the wastes. A chief characteristic is their variability in properties. "Incinerator Standards" published by the Incinerator Institute of America (I.I.A.) lists properties for seven classes of solid wastes (Types 0-6).[1] For Types 0-4 (trash, rubbish, refuse, garbage, animal solids and organic wastes), approximate compositions, moisture content, potential BTU values and other such criteria are fairly well defined. But for semi-liquid and semi-solid wastes no similar criteria are given, with all values marked "variable".

Coleman and Cheek have presented a table of liquid waste properties having ranges, such as from 1 to 10 in percent solids by volume, 0 to 75 in percent by weight and 29 to 2,000 SSU in viscosity at 75°F.[2] Only an estimated maximum was given for heating value, which, incidentally, at 16,000 BTU/lb, is about double that for any of I.I.A. Types 1-4.

This points up the need for classification non-aqueous liquid types. A simple, practical classification based on physical nature would be: (1) solution, (2) suspensions, and (3) sludges and tars. But this and various functional classifications would offer no assistance in developing standards as would a more complex chemical classification to take advantage of the relationship between physical properties and constitution. The wastes are essentially organic in nature, although components in solution of suspension may be organic or inorganic. (Table 1)

A proposed chemical classification would include two major groups based on the major waste component: (1) water soluble organics and (2) water insoluble organics. Insolubles (a relative term) would include three classes as shown in

TABLE 1
Miscellaneous Classifications

Light solvents
Organic tars and still bottoms
Combinations of heavy and light organics
Light hydrocarbons
Gummy organics
Waxy solids
Heavy viscous oils
Pharmaceutical residues
Insecticide residues
Miscellaneous chemicals
Heavy oils and slurries

the following classification outline which provides examples — some generic, some specific:

1. Water soluble organics — acetone, ethyl alcohol
2. Water insoluble organics
   - (a) Hydrocarbons
     - (1) Aliphatics — hexane, kerosene
     - (2) Aromatics — benzene, toluene
   - (b) Simply substituted hydrocarbons — phenol, cresol, benzonitrile
   - (c) Highly substituted derivatives — turpentine, paints, still bottoms, liquid plastics and resins, heavy waste oils and waxy solids.

These classification types are distinguished by their heating values as shown in the following table.

TABLE 2
Heats of Combustion of Typical Liquids

Proposed Type #	*Liquid*	*Heat of Combustion BTU/lb*
1	acetone	13,100
	ethyl alcohol	12,800
2a1	amylene	20,500
	cyclohexane	20,100
	hexane	20,700
2a2	benzene	18,000
	diphenyl	17,400
	toluene	18,200
2b	aniline	15,700
	benzonitrile	15,100
	phenol	14,000
	tar oil	15,000-16,000
2c	glyceryl tributyrate	11,600

It will be noted that the examples for successive types have values of the order of 13,000; 20,000; 18,000; 15,000 and lower.

The classification outline submitted to show possibilities is not yet complete. For example, in the water soluble category no provision is yet made for molecules containing two oxygen atoms, such as for ethylene glycol and acetic acid, or for halogen derivatives. Continuing work on our part will lead to a simple means of treatment for such special cases.

It should be obvious that, for the water soluble category particularly, adjustment will need to be made for water content in relating classification and physical properties. This will be true also when ash or other content of dissolved matter is appreciable, and found in mixtures.

Preliminary calculations indicate that standard relationships can be established between viscosity and type, taking into consideration other properties such as boiling points and molecular weights.

History and Applications

There is little specific mention of incineration of liquids, treated as a "stepchild" of solid waste until within the past years. Undoubtedly, some liquids were burned in England in incinerators before 1900 and to a limited degree in the early incinerators in the United States from the 1930's. Yet only in the past ten years or so have there been reported moves to incinerate liquids, applying modern technology.

The experience of the highly diversified American Cyanamid Company operation at Bound Brook, New Jersey, is believed to be typical of the past. In the early thirties, drums or truck tank loads of solvents would be taken out in the lowlands near the Raritan River and dumped in diked enclosures. Perhaps the drums would not be emptied but would be allowed to disintegrate. Later, solvents would be burned in the open with solid wastes when the night was clear and the wind was blowing the right direction.

In the 1950's, as more volume developed and more industry came into the area, open burning was discontinued. It was soon found that, if a tepee fire of solid wastes were sluggish, a load of solvent or other non-aqueous liquid waste would boost the fire sharply, accompanied by dense clouds of smoke. A separate burner for liquid incineration was developed and designed which minimized objectionable features. Yet increasingly improved New Jersey Standards for air pollution and a corporate desire to be a good neighbor (evidence by leadership through extensive development and investments of more than $6,000,000 in water waste treatment which incidentally provides secondary treatment for a municipal waste treatment plant) — these have led to further action. Incinerator needs have been established and pollution is completely avoided through an outside contractor. It is known that liquid incineration elsewhere in American Cyanamid has been practiced successfully for some years.

Coleman and Cheek, in 1968, report on the experience of Rohm and Haas at Houston, Texas.[2] In the early years of their operation disposal of waste was not a major problem with all refuse, solid and liquid, being burned in open pits in a remote area, though a considerable amount of smoke resulted. Company efforts to have a better disposal method resulted in a specially designed incinerator, the operation of which was reported to be "fully satisfactory."

Because DuPont at Carney's Point, New Jersey, needed to dispose of explosive, hazardous waste nitrocellulose, along with many other solid and liquid wastes, they built an experimental open top incinerator, ruling out a conventional enclosed type. With a specialized design it is reported to have exceptionally good combustion characteristics.[3]

Dow is reported to have built its first incinerator at Midland in 1947.[4] Facilities in 1959 were designed for industrial chemical solid and liquid wastes. Dow has recently designed for 3M an incinerator to burn primarily liquid wastes.

It is known that other companies, large and small, have or are seeking means for non-aqueous liquid waste disposal. This is bringing about a rapid development generally in incinerator design for specific needs.

Technology

Leavesley Industries and some other firms offering incinerators for liquid waste disposal make available units which incorporate redesigned oil burner nozzles. Primary and secondary combustion chambers are designed to fit prescribed needs, as are stack and auxiliaries, such as filters and pumps for the raw feed and scrubbers for combustion gases. Coleman and Cheek have described design features of a typical unit to which earlier reference is made.[2]

Dow's 3M Incinerator is of the rotary kiln type and includes a secondary combustion chamber to consume smoke and odors, a quench chamber, a scrubber, demister and waste water treatment system.[4]

At a National Pollution Control Exposition and Conference in Houston, Texas, in April, 1968, Warshawsky, Lawall and Kiefer reported in detail on the incineration of oily wastes through a fluid-bed reactor, "a relatively recent development."[5]

The need for well designed systems to meet present and future control requirements and the resultant response in meeting the need is illustrated in a brief notation in the Columbia Gas System's 1969 Annual Report in which it is stated that an incinerator for non-aqueous liquid wastes under development for two years is about ready to set up for pilot tests.[6]

Pilot equipment will be used increasingly to improve design and performance. Use of such units will help provide the flexibility in design which is required for I.I.A., Type V liquid because of their wide range in physical properties.

The same principles apply here in respect to meeting these variable needs as recently described by Safford of Atlantic-Richfield in an article entitled "Burner Changes vs. Fuel Changes."[7]

Figures 1 and 2 picture various designs with different feed and discharge methods. Maintenance of high temperature refractories can be a cause of concern to the user when extended firing and alternate cooling are encountered. The furnace design shown has features similar to those in designs of a majority of engineers and refractor manufacturers.

Desirable features include the following:

1. Overall flexibility.
2. Control of outlet temperature independent of the firing rate.
3. Separation of the correct amount of combustion air from the total air flow and feed to the burner for optimum furnace conditions.
4. Achievement of low outlet temperature without lowering the furnace temperature below that desired for perfect combustion.
5. Maintenance of total air flow throughout the total turndown range of the burner.
6. Through air cooled furnace wall, lowering the hot face temperature of the refractory and consequently the cost of maintenance.
7. Through air cooling of the refractory walls, allowing for a thinner wall and a higher heat release in the furnace. The thinner walls, together with lesser volume, drastically reduces the quantity of refractory required.
8. Through less refractory, lowering material cost, and what is more important, lessening the outage time for repairs.
9. Minimum time requirement for warm-up and shutdown.

Alternate Means of Disposal

Some of the early practices in disposition of non-aqueous wastes continue, particularly when smaller quantities are involved. Dumping provides a simple solution and liquids are hauled by drum and tank to remote areas. Containers may be buried with their contents. Yet it is only a matter of time until such outlets inevitably will disappear. Central waste disposal services, as described in a current article in *Engineering Science*

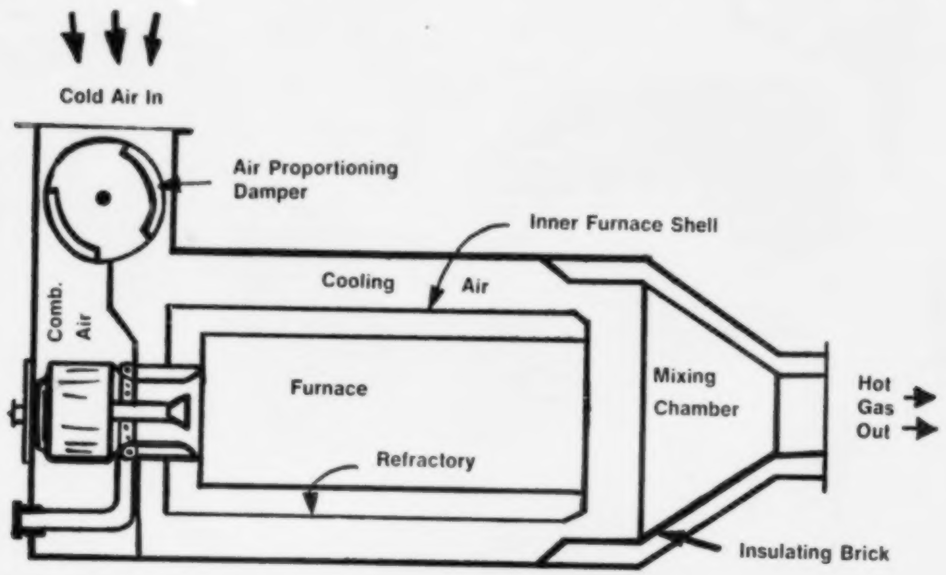
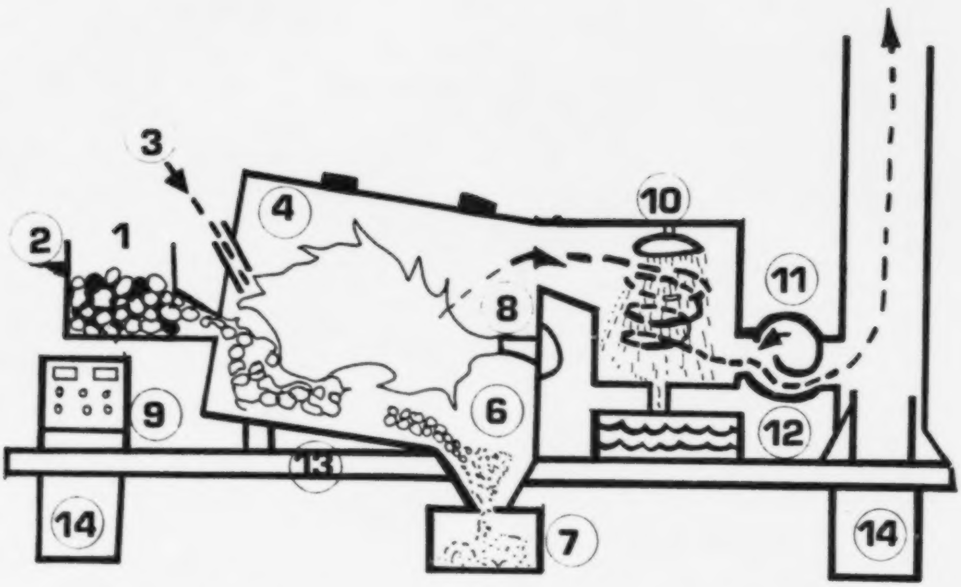

Cold Air In
Air Proportioning Damper
Inner Furnace Shell
Cooling
Air
Comb. Air
Furnace
Mixing Chamber
Hot Gas Out
Refractory
Insulating Brick

Figure 1


3
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7
14

Figure 2

& Technology, will doubtless pick up some of these.[8]

Liquid wastes have been pumped into deep wells, with Dow Chemical at Midland providing a well known example. It has been stressed that for this to be successful there must be unique isolated chambers beneath the earth's surface. Doubtless there are very few cases in which this alternative may be used safely.

Water soluble liquids could be incorporated into liquid waste streams, except that heavy BOD loads are added, and also there may be chemicals dissolved in the liquids which are highly toxic to biological organisms. Even worse would be dumping in streams, lakes and ocean waters.

A recent article by Blanco, Bodbee and Frederick of Oak Ridge National Laboratory describes a process for incorporation of industrial wastes in insoluble media such as asphalt or plastics.[9] Several organic solvent wastes have been so treated, including troublesome highly chlorinated solvents, organic phosphates and polydodecane. Typical industrial residues that would be amenable as solids, solutions or slurries include toxic organics from the pharmaceutical and insecticide industries.

Cost consideration for the Oak Ridge process as discussed shows high costs, as expected. This does point up the need to concentrate residues. In any disposal system this should be done, not only to lower quantities to be processed in waste treatment, but also to recover useable chemicals. Some chemical by-product liquids have been found which have had values exceeding all costs of recovery. Research has been known to obtain new industrial compounds leading to new products and new applications. One example was that of liquid benzothiazole, a prime "stinker" scrubbed from dryer exhaust air in an acid slurry. The slurry was first burned. Research on the benzothiazole led to a derivative which became American Cyanamid's choice speciality Pepton 22® plasticizer for rubber, in continuing use over a period of years. Typically, there was insufficient benzothiazole after a time and more research, development, and alternate supplementary production of the Pepton 22 plasticizer resulted.

Incineration in a fashion designed to eliminate air pollution provides means for permanent disposal of non-aqueous liquid wastes at low operating costs. There is the possibility of recovering significant fuel values, giving further advantage over alternate processes.

SUMMARY

Incineration of non-aqueous liquids, practiced often heretofore as an adjunct to incineration of solids, is entering a period of advanced technology of its own. It is becoming more than ever the process of choice. This is being brought about by ever more rigorous standards for environmental control and by the recognition of advantages of well developed incineration systems.

Recent trade publications offer services in the application of systems designed for specifics. Pilot units are available for testing purposes. An example of a late entry in the field is Dow Engineering Company reportedly being formed by Dow Chemical Company to "initially design and manage incinerator systems for liquid and solid wastes."[4]

It is predicted that incineration will be expanded in industrial non-aqueous liquid waste practice. The trend to more specific, better designed systems will accelerate. It is urged that basic technical information be exchanged and pooled as has been the practice in other fields of environmental control, in order that the art may become a science with sound underlying technology to the benefit of industry and the public alike.

REFERENCES

1. Incinerator Institute of America. *I.I.A. Incinerator Standards*, New York, New York, 1968, p. 5A.

2. Coleman, L. W., and Cheek, L. F. *Chemical Engineering Progress*, Vol. 64, No. 9, September, 1968, pp. 83-87.

3. Anon. *Chemical Processing*, December, 1965, pp. 101-102.

4. Anon. *Chemical and Engineering News*, February 16, 1970, pp. 13-14.

5. Warshawsky, J., Lawall, T. R., and Kiefer, R. J. *Technical Paper NPCEC*, National Pollution Control Exposition and Conference, April, 1968, p. 68-69.

6. *Annual Report for 1969*, Columbia Gas System, Inc.

7. Safford, D. E. *Hydrocarbon Processing*, Vol. 49, No. 2, February, 1970, p. 39.

8. Anon. *Environmental Science and Technology*, Vol. 4, No. 3, March, 1970, p. 195-197.

9. Blanco, R. E., Bodbee, H. W., and Frederick, E. J. *Chemical Engineering Progress*, Vol. 66, No. 2, February, 1970, p. 51-56.

Controlled Air Incineration Of Industrial Solid Waste

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The need for an effective method of on-site disposal of industrial solid waste grows as landfill areas become scarce and contractual hauling arrangements become aggravated by conditions beyond the control of the waste producer. Each disposal problem must be individually assessed but for many firms and industries, on-site incineration will be the best solution.

An increased public awareness of air pollution has resulted in stringent legislation regarding smoke and particulate emissions from incineration processes. Open burning has been declared illegal in almost every state and historical methods of design and operation of conventional incinerators will not meet today's standards.

The multiple-chamber incinerator design standard for Los Angeles County was one of the early technical publications on the subject of incineration process.[1] Design parameters for furnace configuration and combustion air admission were presented in graphical and tabular form for the designer. For many years the retort and in-line design for the Los Angeles multiple chamber incinerators served as the standard by which incinerator performance criteria were evaluated.

Recently, the Department of Health, Education and Welfare has published guidelines for incineration at federal facilities.[2] Under the emission standards now in effect at federal facilities for incinerators having a capacity of 200 pounds per hour or over, these retort and in-line multiple chamber incinerators require the addition of scrubbers to meet the standard of 0.2 grains per standard cubic foot corrected to 12 percent CO_2 excluding the CO_2 contribution of the auxiliary fuel.

Along with the multiple-chamber units, another family of so-called "starved-air" incinerators were developed. They operate on a two-stage combustion principle using incomplete combustion in the primary combustion chamber and complete combustion in the stack. Supplementary air is mixed with the fuel-rich gases in the stack and ignited by means of a pilot burner located in the stack. It can burn cellulose wastes without smoke or particulate emission, however, it does have three distinct disadvantages:

1. Whenever feeding is stopped, the first stage progressively moves toward complete combustion, and combustion temperatures will increase.[3]
2. Its performance on many noncellulose products leaves something to be desired.[4]
3. Residence time in the secondary combustion chamber (stack) may be insufficient for complete combustion of all products leaving the primary combustion chamber.

The volatile content of refuse, that part of the fuel driven off as a gas and burned in suspension — is high, as much as 70 percent, compared to about 10 percent for anthracite and up to 50 percent for bituminous coal. Smoke is a suspension of particulate matter, liquid or solid, in the gaseous products of combustion. Light colored distillation smoke is formed from volatile matter that escapes the fuel bed in a gas stream that is neither ignited nor heated to sufficient temperature to cause continuing pyrolysis. Black smoke is formed when volatile matter is condensed to a liquid aerosol and then heated to such high temperatures in the absence of oxygen that the liquid droplets are converted by continuing pyrolysis in a solid, black, particulate form. Smoke may be eliminated by mixing of the gas with sufficient oxygen at a high enough temperature for complete combustion to follow rapidly. The necessary temperature depends on the degree of pyrolysis. Black smoke may require such high temperatures that, once it is formed, it is impracticable to destroy it by delayed combustion.[5]

From the preceding, it is evident that waste which contains rubber and plastic, producers of black smoke, should be burned in an incinerator with over fire air in the primary combustion chamber.

Feuss and Flower[6] have calculated the residence time in the secondary chamber of a 600 pound per hour incinerator designed to I.I.A. standards to be 1/3 second.[7] In their paper, they recommend a minimum of 1/2 second. Recent work in direct flame fume incineration has indicated that a dwell time of approximately 0.6 seconds with good mixing through a line-type burner flame such that the average downstream temperature is approximately 1400°F will incinerate most hydrocarbon pollutants. A secondary combustion chamber, if designed for a minimum retention time of approximately 2/3 second with good mixing through a burner flame and a positive means of continuously maintaining the temperature above 1400°F, will provide the necessary requirements for complete combustion of the heterogeneous wastes found in industry.

Control of incinerator emissions to meet today's codes can be accomplished by either of two means:

1. A control device on the exhaust, such as a scrubber or

2. A controlled incineration process.

A scrubber, properly designed and maintained, will maintain particulate emission levels below allowable maximum amounts but has certain inherent disadvantages. Water usage is high. A good rule is 1 gallon per minute of scrubber water per 100 pounds per hour of trash burned. In areas where the temperature is likely to go below freezing, the entire scrubbing system must be drained nightly. Acid attack, caused by hydrochloric acid formed through the combustion of chloride containing plastics such as PVC, may damage the scrubber or may require special treatment of the water to neutralize it. Certain areas may forbid the dumping of the contaminated scrubber water into the sewer system without further treatment. If a recycle system is used to conserve water, the nozzles may be subject to plugging and the recycle pumps to excessive maintenance.

A controlled incineration process, if solely dependent upon the incinerator operation, also has certain disadvantages. Improper operation of incinerators has long been recognized by air pollution officials as one of the major causes of air pollution from incinerators. While pollutants from incinerators are only approximately 3 percent of the total atmospheric pollution, complaints from local citizenery may run as high as 40 to 60 percent of the complaints registered at the air pollution control office.[8]

An "operator oriented", automatically controlled air incinerator designed in accordance with the design parameters previously established can be made to function continuously within present day emission standards. Some of the functions that the air control circuit should perform are:

1. Simple, visual indication to operation of proper loading time.

2. Positive, automatic control of the secondary combustion chamber temperature.

3. Underfire air interlock with secondary combustion chamber temperature.

4. Overfire and underfire air interlock with charging door.

5. Secondary combustion chamber auxiliary fuel burner afterburner interlock with charging door.

6. Underfire air interlock with primary combustion chamber temperature.

7. Means of preventing the escape of particulates and flame out the charging door during loading.

Some mention of the final burn down or shut down of an incinerator after a days operation should be made before concluding any discussion of incinerator operation. Normally at the end of the day, the incinerator is full of glowing embers, the fixed carbon remaining to be consumed, the volatiles having been previously burned. If simply shut off at this point, the incinerator will smolder and the unpleasant odors associated with this phase of the operation will result. With the volatile matter consumed, overfire air is no longer required. The secondary combustion chamber temperature must be maintained however. If a means is provided whereby the operator can simply put the incinerator into an automatic shut-down sequence, and, if the control circuit will shut down the incinerator when the temperature in the primary chamber has dropped below a preselected value, then proper continued operation of the incinerator can be assured past the normal working hours giving an added cost benefit to the owner.

The incinerator, having a controlled air circuit as described herein, has been shown to comply with the recent H.E.W. standards when operated at full rated capacity. Effective on-site disposal of industrial solid waste well within the allowable emission limits by controlled air incineration is here today.

REFERENCES

1. Williamson, J. E., et. al. "Multiple-Chamber Incinerator Design Standards for Los Angeles County." October, 1960.

2 "Interim Guide for Good Practice for Incineration at Federal Facilities." National Air Pollution Control Administration Publication, No. AP-46.

3. Monroe, Elmer S., Jr. "Industrial Waste Disposal." 1st Edition, Reinhold Book Corporation, New York, 1968, Chapter 4.

4. Monroe, Elmer S., Jr. "New Developments in Industrial Incineration." *Proceedings 1966 National Incinerator Conference*, ASME, New York, May, 1966, p. 229.

5. Orning, Arthur A. "Principles and Practices of Incineration." 1st Edition, Wiley-Interscience, New York, 1969, Chapter 2.

6. Feuss, James V., and Flower, Franklin B. "Design of Apartment House Incinerators: State of the Art." *Journal of the Air Pollution Control Association*, March, 1969, p. 142.

7. "I.I.A. Incinerator Standards." Incinerator Institute of America, New York, November, 1968.

8. "Waste Management and Control." National Academy of Sciences — National Research Council, Publication No. 1400, 1966, p. 11.

Rotary Type Incinerators for Industrial Solid Waste

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International Incinerator Corp.

The Problem & Criteria

In 1957 International Incinerators was contacted by the Dow Chemical Company of Midland, Michigan, and asked to help solve a problem. The word "problem", inadequately described the unique waste problems found in this chemical industrial complex. The problem turned out to be the disposal of the waste of 1100 products produced in 600 buildings on a 4500 acre site plus inplant trash and refuse.

This was the problem, and it was felt, with our many years experience with our rotary kiln incinerator units, that the company and Dow working together could solve this problem.

In analyzing the many products to be disposed of, those that could be fed into the kiln, those that could be pumped and those that could not be handled by crane were classified.

One of the early conclusions reached was that the normal grates would be unsatisfactory to handle the predominately plastic scrap. This meant a new machine to feed the kiln. The new feeder would have to perform three basic functions with maximum efficiency and maximum safety.

First, it would have to feed the bulk trash and scrap into the kiln at a variable feed rate. Second, it would have to feed 55 gallon drums or fiber paks into the kiln mechanically, with a maximum of safety to the operator. Third, it would have to feed small pellets of plastics at a variable feed rate.

Early tests indicated that 1000°F continuous temperature in the kiln would be necessary to properly ignite the plastic scrap and to minimize black smoke in the effluent of the kiln unit. With the large amount of liquid and semi-liquid wastes to be disposed of, a series of tanks were designed to receive the tars, oils, waste slurries and solvents so that they could be mixed, blended and stored for firing at the burners located at the head end of the kiln. Naturally this operation would require the supervision of an experienced chemical engineer to properly control the mixing and blending of the tars to maintain a burnable product for continuous firing in the kiln. At the time, no steam was available at the proposed plant sites and this presented another problem in air firing of the thick tar slurries at the burners. These tars were coded in the name of "applebutter", since this was what they looked like in appearance and consistency.

After several months of study the design criteria and plant performance requirements were studied and analyzed. It had to be decided if the challenge could be accepted, and if the requirements of this project could be met. There was little state of the art in 1957 other than the plant experience of Dow with their own equipment. This same problem could be foreseen arising with other industries in the future, and the foresight of Dow in trying to solve its industrial solid waste problem at an early date could only be admired, since there was no prodding and pressure from local or state authorities. The decision was made, and a contract was worked out, whereby International would do the engineering, purchase of equipment, supervision of construction, and conduct performance tests for this project.

Engineering

To handle the many solid products such as, plastic styrofoam logs, plastic sheets, wood palets, plant trash and cafeteria waste, the use of the pit and crane concept used in municipal plants was adopted. This would allow the crane operator to mix and blend the various items of this particular solid waste and to make it a more homogenous mix to help control the BTU content per pound. Heat release control of these variable products would be essential for this project. To accomplish this function, a feeder was designed that would allow the craneman to feed a hopper mixed waste to a visible level in the hopper, thereby providing an air seal at the feeder before discharge into the kiln.

A part of the feeder would be a conveyor to transfer the bulk trash from under the hopper to a discharge point above the second feed chute feeding the kiln. This conveyor would be self contained in the feeder and be driven by a variable speed motor and gear reducer. This would accomplish the first basic requirement of the new feeder. Several engineering decisions were required for this primary unit, such as height of the air seal column, slope of the conveyor, length of the conveyor, speed range of the conveyor, width of the conveyor, and the height of the conveyor flight spikes.

In developing the pak and drum feeder to accomplish the second basic function of the new feeder, the prime requirement was safety. Previous experience at Dow's old unit showed that some of the drums filled with material of semisolid high BTU waste would sometimes react like solid fuel rockets and launch themselves up the feed chute and through the building roof if improperly fed into the kiln. To avoid this problem the new unit must always introduce the drums or paks bottom first into the kiln. It was also decided to classify each drum or pak to control BTU heat release by quantity content, viscosity, and type of material. The operator was provided air lock safety control and push button sequencing of this function to assure safety. The motive system for this operation was established as hydraulic since this provided a more flexible speed control for the sequential operations of the pak and drum feeder.

The pak and drum feeder was located to the side and behind the discharge point of the feeder conveyor, since it had been established that the feeder conveyor would not be operating when the pak and drum feeder was in operation. The configuration and control of these two elements were to be such that only one element could be in operation at any one time. Basically, the unit would allow the operator to place a drum or pak on a horizontal rotating metal grid, close the air lock, station himself at a safety console and operate a push button station to properly discharge the drum or pak into the kiln at the right speed, position and maximum safety as required by the criteria.

To accomplish the third primary function of the feeder, feeding pelletized plastics, a separate section of the storage pit was designed to receive the pelletized plastic; a hopper with a live bottom and transfer conveyor to the top of the trash feeder was evolved. By variable speed control of the conveyors the pelletized plastic could be fed in on top of the bulk trash in the primary feeder.

Other features incorporated into the feeder were a fire protection system, including detecting units, a heat surge (explosion) vent, and provision for primary air for combustion from either outside or inside the building with damper control. A special port at the secondary feed chute was also provided for the disposal of any unusual or (hot) items from the research laboratories.

The feeder unit was to be located under the feed hoppers and on a floor level designated as the operating floor which was to be some three feet above the top of the rotary kiln. To connect the feeder to the rotary kiln a secondary feed chute was designed to accommodate the bulk trash and paks and drums from the feeder. At the end of this chute and next to the feed end of the kiln, a kiln seal plate was provided. Mounted on this seal plate on each side of the chute would be the burners for firing the burnable tars from the storage tanks.

Since the bulk trash could be blended in the pit, it was possible to rate the feeder in tons per hour, and this was established at 100 tons per twenty-four hours. By classification of the paks and drums, BTU rates per hour could be established, and feed rate would be in drums per hour. To accommodate the three basic functions the rotary kiln could only be designed on the basis of

BTU heat release per hour. By heat balance calculations the kiln was then rated at 65 million BTU per hour based on feeding 100 tons per day of bulk trash and tars or feeding paks and drums at a feed rate of 12 per hour and tars at a feed rate of 5 G.P.M. Feed rates for the tars were also variable from 0 to 5 G.P.M.

In order to feed the bulky waste and to allow space for the burners, the kiln diameter was set at 12'9" and the length at 35'0". Slope of the kiln could be from 0" to 6" in its length. The kiln would be lined with 9" of super duty firebrick and have 2 1/2" of insulating firebrick next to the shell. Since the kiln would be outside and subject to the elements of weather, shell temperature should be between 400°F and 600°F, and this established the reason for the insulating brick.

The discharge end of the kiln was contained in a refractory lined mixing chamber and discharge housing. Residue from the burning function in the kiln was to be discharged into a water filled conveyor and conveyed to a separator system where the metal could be separated from the residue by the use of a bar screen. The hot 2000°F gases from the kiln would then flow into the refractory lined mixing chamber for turbulence, and then into a refractory lined wet baffle scrubber chamber where they would be scrubbed with water prior to flow into the chimney. The chimney was sized for the draft requirements of two units and was to be 200 feet high.

In addition to the primary air supply at the feeder, forced air and turbulent air were to be supplied at the feed end of the kiln by forced draft fans. Turbulent air was to be supplied at the mixing chamber by a separate forced air fan.

Draft control for the unit would be by a refractory damper between the wet baffle scrubber and the 200 foot high natural draft chimney. The damper would be motorized for remote operation from the main control panel on the operating floor.

Three control panels were to be provided, one for operating the main feeder with the variable speed control units for the feeder and the rotary kiln, the forced air fans and the main damper. The panel would also contain the temperature indicators and recorders and the draft gauges. The second panel, located on the side of the feeder, would be to operate the pak and drum feed unit. The third panel, located at the tar burners, would contain the necessary control and safety devices for the burners.

The enclosed areas of the building would include the storage pit, the main feeder and pak and drum feeder and the pak and drum storage area. Also provided in the building enclosure would be the necessary offices, lab room, shop, shower room, toilets, and lunch room. The building would be sized for the future installation of a second unit. The other enclosed area would be the residue conveyor area separated from the main building.

Construction

With the engineering work completed and bids received International was awarded contracts for the equipment and its installation. Dow awarded contracts for the remainder of the work.

Construction was completed in January 1959 and the plant was ready for operation.

Operation

Initial operation and testing indicated that the design and specification requirements could be exceeded with the equipment as installed. Stack emission was well under the codes of that time.

Results

The results of this joint venture provided Dow with the solution to its waste problem. It had taken two years and over $2.5 million dollars, but now Dow could conform to its philosophy that industry must be responsible for its own waste problems, not just some, but all, including solid waste.

CONCLUSIONS

International had hoped that other industries with solid waste problems would follow the Dow philosophy, although it is realized that the cost factors and the problem of selling management on buying machinery that does not make, or help make a saleable product.

Through the years the rotary kiln system has been discussed with other industries, but until the recent air and water pollution acts and regulations, not many industries wanted to spend the necessary funds for solid waste disposal.

It is apparent from the success of the Dow unit with its ability to dispose of solid and liquid industrial waste that industries, either alone, or jointly, could use the rotary kiln system to solve many problems with one system. This has happened in St. Paul where International is furnishing and installing a rotary kiln unit for the 3M Company. This project is a joint venture where 3M and Dow are working together to solve an industrial problem.

Bioflocculation Mechanisms in the Separation of Biomass from Aqueous Waste Treatment Systems

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Ever since Arden & Lockett[1] introduced the concept of the activated sludge process in 1913, the sanitary engineer has been intrigued with the mechanisms of bioflocculation in wastewater treatment. This process has proved to be successful when the biomass produced (a) rapidly sorbs organic matter from the wastewater, and (b) separates from the liquid leaving a clear supernatant. The first of these criteria deals with the transport of the organics, oxygen, and nutrients into and out of the active biomass, the chemical and biochemical kinetics of substrate conversion and the metabolic and physiological processes occurring in the biomass. The second criteria, which will be discussed herein, deals with the capacity of the microorganisms within the process to form flocculent suspensions which will survive the physical, chemical and biological stresses of the system.

The literature is replete with reports on the problems attendant with solid-liquid separation of activated sludge. Poor solid-liquid separation of activated sludge has long been termed sludge bulking, and two types of bulking sludge are often recognized: (a) flocculated sludge with low settling rates, and (b) filamentous sludge with low settling rates. Pipes[2,3] recently discussed filamentous bulking in detail and cited a number of cause and effect relationships in the filamentous bulking of activated sludge. More recently, Farquhar[4] discussed the importance of the identification of the filamentous organism causing sludge bulking prior to taking remedial measures. A perusal of the literature suggested that filamentous bulking was not caused by a universally singular organism and thereby could not be solved by a universally singular solution. Farquhar demonstrated that the fundamental understanding of the physiology of the filamentous organism, *Thiothrix* isolated from a bulking activated sludge helped to establish remedial measures for the control of *Thiothrix* bulking.

The problems with bulking of non-filamentous sludges, often termed zoogloeal bulking, are also complex and require a fundamental understanding of the mechanisms of bioflocculation. It is recognized that activated sludge is a dynamic, heterogeneous population of microorganisms. Yet, if problems attendant with the integrity of the microbiological floccules are to be solved, a fundamental approach must be taken. This has been the philosophy which has governed much of the productive research on bioflocculation. Far too often in the past, bioflocculation mechanisms have been speculative or even teleological.

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Mechanisms of Microbial Flocculation

At this point, it would be useful to define what is meant by the term flocculation. The literature does not often carefully define the type of association of microorganisms to which it is addressing itself. Thus the words agglomerate, aggregate, agglutinate and flocculate are often used interchangeably. In the activated sludge process, successful bioflocculation is only met when the resultant aggregation (a) is tightly bound and not subject to fracture under the shear forces normally encountered in aeration tanks or pumps, and (b) is of a sufficiently high enough specific gravity so that it will easily separate from the liquid when subject to low velocity fields. Thus, in this text, flocculation is defined as the formation of relatively large floccules (20 μ nominal diameter and greater than 10^3 cells) which do not disintegrate into smaller floccules upon vigorous agitation (shear rates in excess of approximately 50 sec^{-1} or energy dissipation per unit volume of about 0.02 hp/1000 gal).

Many microorganisms produce a transparent, gelatinous or slimy capsule which is ordinarily demonstrable only when cells are growing in aggregates. Among these organisms are certain species of the genus *Alkaligenes*, *Bacillus*, *Streptococcus*, *Aerobacter*, *Pseudomonas* and *Leuconostoc*. These organisms produce capsular material under certain environmental conditions and may aggregate into small cell clusters of 10 to 100 organisms. In most cases these microscopic aggregates cannot be considered floc by our definition and most certainly would not offer a substantially tenacious matrix for large cell floccules. Thus, aggregates of *Aerobacter aerogenes* were easily disrupted by mild agitation and would not induce significant flocculation of dispersed cultures of *Zoogloea ramigera* (I-16m) under a number of growth conditions.[5]

Although the mechanism which causes the loose aggregation of microorganisms is of interest, there is some question as to whether these mechanisms explain the tenacious aggregation of microbial floc found in aeration tanks. In the sanitary engineering literature, a number of mechanisms for microbial aggregation have been proposed. Briefly these may be categorized as follows:

1. Presence of gelatinous or capsular matrix
2. Colloidal theories
3. Protozoan theories
4. Mechanical entanglement
5. Inert matrix theories
6. Salt bridging
7. Low energy concepts
8. Polymer formation theories

These concepts have been recently reviewed by Boyle et al[6] in 1968. Since that time, the predominance of work done in bioflocculation in wastewaters has dealt with the polymer formation theories.

The polymer formation theories are based primarily on the principal that microbial aggregation is caused by the interaction of natural polymers produced by the microbes which cause bridging of individual cells. Katchalsky[7] reported that *E. coli* and *S. aureus* were successfully flocculated with polylysine. Hodge and Metcalf[8] flocculated bacteria with hydrophilic polymers of both ionic and non-ionic structure. Shortly thereafter, Tenny and Stumm[9] proposed that bioflocculation could be explained in terms of polyelectrolyte interaction. Wessmann and Miller[10] found that the aggregation of *Pasteurella pestis* was caused by polymerization of extracellular nucleic acids excreted by the cells. Busch and Stumm[11], working with pure cultures of *E. coli* and *A. aerogenes* demonstrated that bacteria could be aggregated with anionic and nonionic polyelectrolytes as well as the polyglutamic acid with no net charge at pH 4.0. These authors further demonstrated that centrifugation of glucose-fed activated sludge and ethanol precipitation of the supernatant resulted in a polymeric substance which flocculated both SiO_2 and dispersed *A. aerogenes* cultures. No definitive effort was made to identify the substance. It was proposed that cell aggregation was the result of specific adsorption of polymers or polymer segments on the cell surface resulting in bridging of the polymer chains between cells. It is important to note that the cell aggregates in these studies were loosely bound and no mention was made of aggregate size.

During the period 1963-1968, detailed studies on the morphology, physiology and floc forming characteristics of pure culture floc forming organisms isolated from activated sludge were conducted at the University of Wisconsin. Details of these studies appear in the literature[5,6,12,13]. In summary, it was found that pure cultures of *Zoogloea ramigeria* I-16m accumulated an intracellular polymer, poly β hydroxylbutyric acid (PHB). It was observed that this polymer accumulated in the cell preceding floc formation and that blockage of PHB synthesis inhibited cell flocculation. In addition, it was shown that endogenous dissimilation of the accumulated polymer in flocculated cells resulted in deflocculation. The floc that formed was tenacious, its shape and size being dependent upon the substrate characteristics and shear rates during growth (Figure 1).

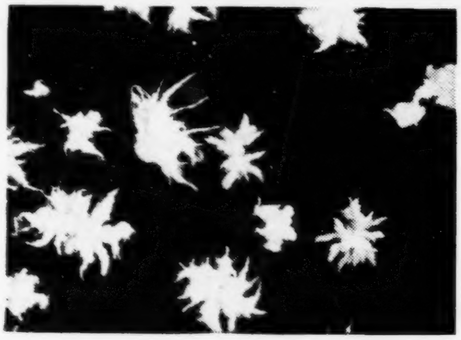

Figure 1: Flocs of *Zoogloea Ramigera* I-16m Embedded in 0.2 Percent Purified Agar (Magnification 30X)

The mechanism of attachment of the individual cells within the floccules is still subject to question. It was proposed that initial attachment may occur due to the incomplete division of the cells (Figure 2 and 3). In the growth of these microorganisms it was noted that rapid PHB accumulation caused cells to divide incompletely resulting in irregular chains of cells. Once microflocs were formed, it was speculated that a more positive attachment between cells was achieved through ester bonding of the polyester linked PHB granules. This attachment may occur through a partial rupturing of the cell membrane in the pleomorphic cells. It was further speculated that PHB may be exposed between the cell wall and the cell membrane in the folds of the membrane called mesosomes. Mesosomes have been shown to be active metabolic sites within a number of bacteria. Polymeric binding would occur through the relatively porous cell wall at these localized points of activity. Presently there is no visible evidence to substantiate this hypothesis.

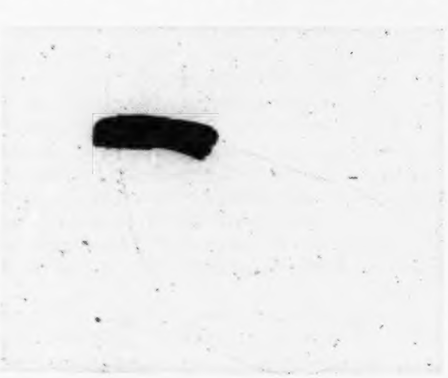

Figure 2: . Electron Micrograph of a Dividing Cell of Z. *Ramigera* I-16m With Flagella at Polar and Lateral Positions (Magnification 7,200X)

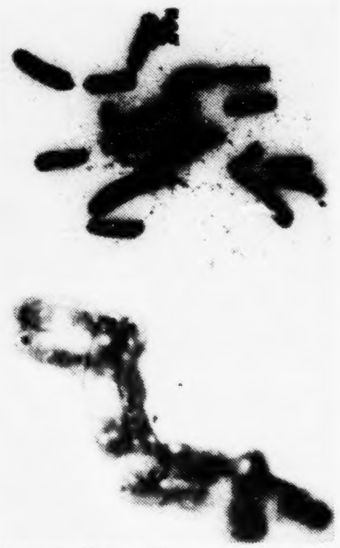

Figure 3: Electron Micrograph of Actively Dividing Cells of *Z. Ramigera* I-16m From Standing Broth Cultures (Magnification: Upper 14,800X, Lower 7,200X)

Recently, Friedman, et al[14,15] presented a series of electron photomicrographs of flocs of several strains of *Z. ramigera*, *Z. filipendula*, *Pseudomonas denitrificans* and an unidentified gram negative rod, C-22-4. Some of these isolates possessed a capsular matrix that was demonstrable with normal bright field microscopy and appropriate stains. Other of the isolates, including *Z. ramigera* I-16m, did not exhibit a capsule with normal procedures, a fact which was puzzling since it was observed that the individual cells within the floc seemed to move together as if attached (Figure 4). Friedman, et al. stained this latter group of isolates with the fluorescent dye, Paper White BP and photographed them through an ultraviolet microscope. With this procedure, an exocellular matrix was demonstrated.

Electron photomicrographs of all flocs demonstrated the existence of a fibrillar extracellular matrix (Figure 5). This matrix was subjected to

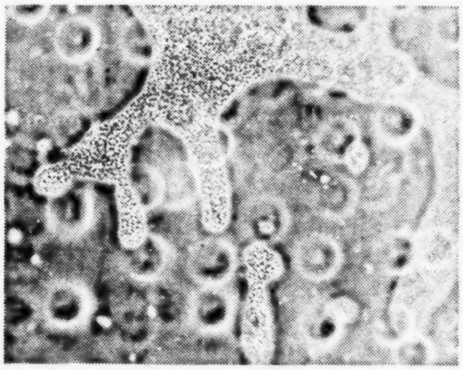

Figure 4: Wet Mount of *Zoogloea Ramigera* I-16m Showing Typical Fingerlike Projections

chemical and biochemical analyses, but was not clearly identified. The material is probably not cellulose and it is proposed that it is some form of a polyhydroxysugar. These authors proposed that the fibrillar polymer matrix may act as a polyelectrolyte, adsorbing to cell surfaces and bridging between individual cells. In addition, they proposed that these fibrils may act to entangle individual cells within the matrix. In any event, the existence of these fibrils, either being extruded from the cells or being extracellularly produced, tends to further support a polymeric bridging hypothesis. It is yet to be demonstrated how the presence (or absence) of PHB is related to the flocculation process or to the presence of the extracellular fibrils.

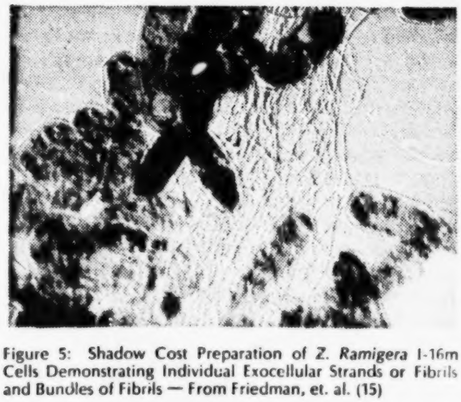

Figure 5: Shadow Cost Preparation of *Z. Ramigera* I-16m Cells Demonstrating Individual Exocellular Strands or Fibrils and Bundles of Fibrils — From Friedman, et. al. (15)

Factors Affecting Bioflocculation

The factors most often noted to cause the deflocculation to heterogeneous microbial flocs in activated sludge include reduced dissolved oxygen concentrations, high mixed liquor solids concentrations, high sludge loading ratios (F/M) and excessively high or low carbon to nitrogen ratios. In addition, factors that resulted in excessively high shear forces on the floc, e.g. very high aeration rates, often were reported to cause floc dispersion.

In pure culture studies of floc-forming organisms, a number of variables have been reported to effect bioflocculation. Carbon to nitrogen ratios exceeding 30 to 1 or less than 10 to 1 were shown to be detrimental to floc formation of *Zoogloea ramigera* I-16m grown in a basal medium containing glucose as the sole carbon source and ammonia nitrogen as the nitrogen source.[5] However, the nature of the carbon and nitrogen sources was critical in the evaluation of effective C/N ratios. Thus, a completely dispersed form of growth of *Z. ramigera* was obtained with low concentrations of arginine (200-500 mg/l), but excellent flocculation resulted at arginine concentrations greater than 1000 mg/l. In both instances, of course, the calculated available C/N ratio was the same (C/N = 5.0 assuming that the organism uses only the primary amino group of arginine).

The effect of cation concentration on bioflocculation has been reported by Busch and Stumm[11], Tezuka[16,17], Angelbeck and Kirsh[18], Crabtree[5], and Braun[19]. Both Busch and Stumm and Tezuka[16] reported that the cations of Mg^{++} and Ca^{++} induced aggregation of microbial cells. Busch and Stumm, using cultures of *E. coli* and *A. aerogenes*, proposed that this cation dependency was due to complex or ion pair formation between functional groups of the polyelectrolyte (either added or naturally produced) and the "counter ion" in the vicinity of the bacterial cell. Tezuka[17], however, indicated that floccules of a species of *Flavobacterium* could be formed merely by the addition of cations to the dispersed suspension. Redispersion was obtained immediately upon placing these floccules in deionized water. Thus, he proposed that flocculation of this culture was a physiochemical process rather than a physiological one.

Crabtree reported that *Z. ramigera* I-16m required K^+, Mg^{2+}, PO_4^{3-} and SO_4^{2-} for growth, but he did not investigate the influence of cation concentration on flocculation. Braun[19] conducted a series of shake flask experiments with *Zoogloea ramigera* I-16m to determine the influence of

Mg^{++} concentration on growth rates and flocculation rates. As Mg^{++} concentrations were increased from 2.6 mg/l to 867 mg/l in a basal medium containing 1000 mg/l arginine, the aggregation of the cells decreased from approximately 20 percent dispersed cells to 90 percent dispersed cells. Tezuka[17] reported similar results with a floc-forming bacteria isolated from activated sludge. Bioflocculation was inhibited in a glucose medium at Mg^{++} concentrations as low as 2 mg/l. Angelbeck and Kirsch[18] found that Ca^{++} and Mg^{++} inhibited flocculation of two strains of non-slime-forming strains of *Zoogloea ramigera* in a peptone-beef extract media at pH 6.0. Calcium was reported to be 10 times as effective as Mg^{++}, and neither cation would deflocculate a previously flocculated culture.

The role of cations in the bioflocculation of bacteria is yet unclear. There is considerable evidence that cations may be involved in metabolic pathways resulting in the interference of the production of a constituent causing bacterial aggregation. However, the physiochemical process for certain bacterial species cannot be discounted.

The importance of hydrogen ion concentration in bioflocculation has been alluded to by Crabtree. In a media containing glucose as a sole carbon source and ammonium nitrate as a nitrogen source (C/N = 20) he found that excellent flocculation occurred at pH values between 7.0 and 8.5. Flocculation at pH values between 6.5 and 9.0 was poor and it was noted that PHB accumulations were significantly lower at these pH values. Additional studies with the basal arginine media (200 mg/l) adjusted to pH 7.0, 5.5, and 9.0 indicated that glucose addition after dispersed cell growth reached 2×10^9 cells/ml resulted in excellent flocculation only at pH 7.0. Again, polymer synthesis was depressed at the lower and higher pH values although there was little difference in viable cell counts. Angelbeck and Kirsch found that cultures of *Zoogloea ramigera* grown on peptone-beef extract without carbohydrate supplementation flocculated more effectively at pH 6.0 than at 7.0. Dispersed cells grown at pH 7.0 and placed in media at pH 6.0 did not effectively flocculate.

The apparent differences noted in the effects of hydrogen ion concentration on identical cultures of *Zoogloea* are not immediately apparent. The physiochemical aggregation of gram negative bacterial cultures caused by pH reduction is well known. Neutralization of charge associated with the muramic acid, amino sugar exocellular slime layer associated with gram negative bacteria, will cause the rapid aggregation and precipitation of the cells. It is significant to note, however, that the metabolic rates of the organisms are affected and that these two studies were conducted using different types of substrate. The undefined content of the "peptone-beef extract" makes it difficult to speculate on the different metabolic processes that may occur.

Considerable effort has been made to establish steady-state continuous culture techniques for *Zoogloea ramigera* I-16m[19]. During this effort it was found that reactor nutrient loading (mg substrate per viable cell per hour) controlled the state of cell flocculation. Furthermore, it was found that dispersed cell growth rates were considerably greater than those of flocculated cells. Nutrient transport did not control this rate, but it was hypothesized that toxic product transport out of the floc affected the overall growth rate. Attempts to operate a steady-state continuous flow reactor were unsuccessful primarily due to a cycling of the cells through various levels of flocculation. Growth and nutrient removal rates were dependent not only on nutrient concentrations but also on PHB accumulations, floc size distribution and the ratio of dispersed cells to flocculant cells. Details of these studies appear elsewhere but it is significant to note that bioflocculation was dependent upon the characteristics of the floc as well as the substrate.

Quantitative Description of Bioflocculation

One may write a general expression for the rate of increase of numbers of k-aggregates per unit volume as

$$\frac{dn_k}{dt} = C_k + D_k + R_k$$

where n_k = number concentration of floccules containing a total k bacteria each at time, t.

C_k = net rate of formation of k-floccules resulting from collison.

D_k = net rate of formation of k-floccules resulting from disruption of preformed floccules.

R_k = net rate of formation of k-floccules resulting from bacterial replication.

A detailed discussion of the terms of this equation has been recently reviewed.[6] Presently, efforts have been undertaken to better characterize the rates of flocculation due to collision C_k, of *Zoogloea ramigera* I-16m[20]. A closed form analytical solution which predicts the number frequency of every size of floccules during the entire course of flocculation under shear was obtained.

$$\frac{n_k}{N} = \frac{k^{k-1}}{k!}\left[\frac{1-N}{no}\right]^{k-1}\left(\exp\left(\frac{N}{no}-1\right)^{k}\right)$$

where no = the initial number of primary particles

N = total number of floccules contained in the system at any time.

This equation was developed based on the assumption of a mono-dispersed suspension of spherical, equal sized particles. It was further assumed that gravitational effects and interparticle repulsive forces were negligible, that all collisions resulted in adhesion, and that no disruption of aggregates occurs. The motion of the suspending fluid was characterized by one-dimensional flow with constant shear rate, and the particle motions were along straight lines independent of each other up to the point of contact.

Experiments were conducted within a coni-cylindrical viscometric apparatus whose flow fields were characterized by equal and nearly constant shear rates. The results of this study were briefly as follows:

For the majority of experimental runs, cumulative size distributions tended to approach the limiting form predicted by the model. This model was not adequately tested in the early stages of flocculation but agreement between the model and experimental observation for small values of N/no were encouraging. During early stages of flocculation within the apparatus, small flocs tended to be non-spherical and exhibited pronounced eccentricity. As duration of applied shear increased, flocs exhibited significant consolidation approaching an isometric shape. The pronounced non-sphericity of the flocs in the early stages of aggregation resulted in higher collision rates than predicted by the model which was derived for spherical particles.

Conditions of flocculation were controlled so that no growth occurred during experimental runs; therefore R_k approached zero. Floccules up to 2-3 mm in nominal diameter were not disrupted at shear rates of 75 sec^{-1}. In the viscometric apparatus shear rates were less than 15 sec^{-1}, therefore D_k also approached zero.

Phase contrast microscopic observations indicated that collision efficiencies for most floc-floc interactions approached 1.0. Single cells appeared to follow streamlines around aggregates, thus avoiding contact. Aged flocs (greater than 4 hours of agitation after glucose addition) were not prone to adhere upon collision. Attempts to flocculate *Zoogloea ramigera* I-16m in 2% hydroxyethyl cellulose (HEC) solution with a viscosity of approximately 174 cp were unsuccessful. HEC did not affect cell viability and it was speculated that it altered the surface chemistry of the cells.

SUMMARY

In this rather brief and cursory review of current activity in the investigation of mechanisms of bioflocculation in wastewater systems, it is immediately apparent that the state of the art is still in its infancy. Qualitative mechanisms are, at best, very complex even in pure culture systems. Nor is there any question that these mechanisms are considerably more complex and diverse in heterogeneous systems such as activated sludge. The mechanism of flocculation under any given set of conditions may be physiological or physiochemical depending upon the organism and system characteristics. There is undoubtedly a combination of mechanisms involved in the bioflocculation of activated sludge and predominant mechanisms will vary with waste and process characteristics. There is considerably support for "polymerization" as an important mechanism in the tenacious flocculation of microorganisms. The gelatinous or slime matrix that is observed is likely a secondary effect rather than a primary causative agent in aggregation of these floc.

The analytical description of bioflocculation is also highly complex and relatively undeveloped. Most efforts to date in bioflocculation have been directed to rates of aggregation, and little data is available on the effect of aggregate disruption and cell replication within the aggregate. Recent studies of shear-induced flocculation using pure culture bacteria are contributing to a more fundamental prediction of bioflocculation.

REFERENCES

1. Arden, E. and W. T. Lockett. "Experiments on the Oxidation of Sewage Without the Aid of Filters", J. Soc. Chem. Ind. *33*: 523. (1914).

2. Pipes, W. O., "Bulking of Activated Sludge" in *Advances in Applied Microbiology* (Ed. Wayne W. Umbreit), Academic Press, N.Y., 9, 185, 1967.

3. Pipes, W. O., "Types of Activated Sludge Which Separate Poorly", J. Wat. Pol. Cont. Fed. *41*, 714, 1969.

4. Farquhar, G. J., "Filamentous Microorganisms in Activated Sludge", Ph.D. Thesis, University of Wisconsin (1968).

5. Crabtree, K., "Morphological and Biochemical Studies of *Zoogloea ramigera* Species in Pure Culture", Ph.D. Thesis, University of Wisconsin, (1965).

6. Boyle, W. C., et al. "Flocculation Phenomona in Biological Systems" in *Advances in Water Quality Improvement*, Water Resources Symposium No. 1 (Ed. by E. F. Gloyna and W. W. Eckenfelder) University of Texas Press, Austin, Texas, p. 287 (1968).

7. Katchalsky, A., "Polyelectrolytes", Endeavor, *12*, 90 (1953).

8. Hodge, H. M. and S. N. Metcalfe, Jr., "Flocculation of Bacteria by Hydrophilic Colloids", J. Bacterial, 75, 485 (1958).

9. Tenney, M. W. and W. Stumm, "Chemical Flocculation of Microorganisms in Biological Waste Treatment", 19th Purdue Ind. Waste Conf., 1963 and J. Water Poll. Cont. Fed., *37*, 1370 (1965).

10. Wessman, G. E. and D. J. Miller, "Biochemical and Physical Changes in Shaken Cultures of *Pasteurella pestis*", Appl. Microbial, 14, 636 (1966).

11. Busch, P. L. and W. Stumm, "Chemical Interactions in the Aggregation of Bacteria-Bioflocculation in Waste Treatment", Environ. Science & Tech., *2*, 49 (1968).

12. Crabtree, K., E. McCoy, W. C. Boyle and G. A. Rohlich, "Isolation, Identification and Metabolic Role of the Sudanophilic Granules of *Zoogloea ramigera*", Appl. Microbial, *13*, 218 (1965).

13. Crabtree, K., W. C. Boyle, E. McCoy, and G. A. Rohlich, "A Mechanism of Floc Formation by *Zoogloea ramigera*", J. Water Poll. Cont. Fed., 38, 1968 (1966).

14. Friedman, B. A., P. R. Dugan, R. M. Pfister and C. C. Remsen, "Fine Structure and Composition of the Zoogloeal Matrix Surrounding *Zoogloea ramigera*", J. Bact., 96, 2144, (1968).

15. Friedman, B. A., P. R. Dugan, R. M. Pfister and C. C. Remsen, "Structure of Exocellular Polymers and Their Relationship to Bacterial Flocculation", J. Bact. 98, 1328 (1969).

16. Tezuka, Y., "Cation-Dependent Flocculation in a *Flavobacterium* Species Predominant in Activated Sludge", Appl. Microbial, *17*, 222 (1969).

17. Tezuka, Y., "Magnesium Ion as a Factor Governing Bacterial Flocculation", Appl. Microbial, *15*, 1256 (1967).

18. Angelbeck, D. I., and Kirsch, E. J., "Influence of pH and Metal Cations on Aggregative Growth of Non-Slime Forming Strains of *Zoogloea ramigera*", Appl. Microbial, *17*, 435 (1969).

19. Braun, H. and W. C. Boyle, "Continuous Culture of the Floc-Forming Bacterium, *Zoogloea ramigera*", In preparation.

20. Iaccarino, E. P., "Shear-Induced Flocculation of Bacteria", Ph.D. Thesis, University of Wisconsin, (March 1969).

The Use of Synthetic Organic Polyelectrolytes to Handle Biomass Sludges

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The use of synthetic organic polyelectrolytes to concentrate and dewater biomass sludges is becoming very common in industrial solids and waste plant installations. These synthetic organic polyelectrolytes are available in a wide variety of molecular weights, types of functionality and amounts of functionality. Regardless of these variations, all polyelectrolyte flocculants are designed to do the same thing; that is, they cause agglomeration of the fine suspended particles in the system. When organic polyelectrolytes are used in these systems: (1) they give the agglomerates more rapid sedimentation rates, (2) they increase floc shear stabilities, (3) they reduce waters of hydration.[1,2] These important solids modifications are presumably accomplished by the well-known adsorption — bridging mechanism of polyelectrolytes (**Figure 1**).[3,4]

A few general remarks about biological sludges should be made before discussing their treatment with synthetic organic polyelectrolytes. Biological sludge systems have notoriously poor sedimentation rates. Since most of the biological cell is water, it follows that as the relative concentration of the biological matter in a sludge system increases, the density of that system approaches that of water. In 100 percent waste activated systems, either induced sedimentation or induced flotation techniques are necessary to obtain reasonable solids concentrations and separation rates. Also, biological cells are highly anionic. Therefore, as the biological content increases, higher amounts of cationic functionality may be required before reasonable solids destabilizations may be observed. The use of anionic materials in biomass sludges has been very unsuccessful, and regardless of molecular weight, large amounts of low cationic functional materials are often required to successfully treat these systems. Third, biomass agglomerations are very shear sensitive. Some of us have seen cases where even the convection currents in secondary clarifiers are strong enough to disrupt secondary suspended solids flocs and cause severe solids carryover problems. This shear sensitivity is probably due to biological cell deformation, low surface bond strengths, and high anionic charge densities on the biocell surfaces. Therefore, any system used to treat biomass sludges must be carefully selected to modulate these typical characteristics of secondary solids systems.

Suspended solids concentration techniques are very important prerequisites prior to the more elaborate and costly dewatering operations.[5]

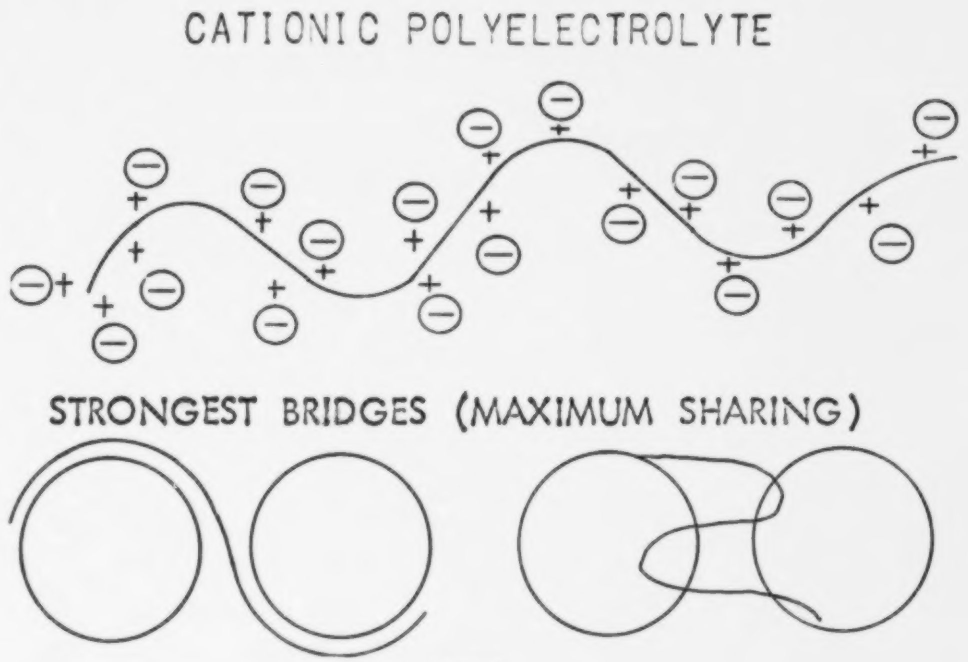

Figure 1

Biomass sludges have been successfully concentrated by dissolved air flotation units, sludge thickeners, and elutriation basins.[6, 7]

One of the more common techniques for thickening 100 percent waste activated sludge is by dissolved air flotation (Figure 2). In this operation, solids attach themselves to rising air bubbles and are floated to the surface. This operation takes advantage of the low density characteristics of biological systems, and reasonable waste activated blanket solids contents have been obtained by this method. Polyelectrolytes may improve solids rise rates and blanket solids concentrations in this operation. Polyelectrolytes can do this by (1) increasing the floc size to encourage steric air capture, (2) disrupting hydration layers, (3) improving floc stability characteristics, (4) aiding bond formation between solids and air bubbles. The air attachment phenomenon is often more apparent when polyelectrolytes exhibit both hydrophobic and hydrophilic characteristics. While many polyelectrolytes are commercially available today which may improve dissolved air flotation operations, significantly more effective polyelectrolytes for this application are expected to enter the market in the next few years. Table 1 emphasizes the effectiveness of a polyelectrolyte in this type of system resulting in decreased subnatant suspended solids and substantially increased float cake solids. Suspended solids rise rates were also dramatically improved in this operation with the use of this material.

Polyelectrolytes have also proven to be useful in anaerobically digested biological solids systems (either primary or mixed waste systems). For example, an elutriation technique is a common method for removing interfering soluble ions (e.g., alkalinity) and concentrating suspended solids systems.[8, 9] This dilution method is often used in biological sludge systems. For example, an anaerobic digested mixed sludge was diluted with two parts of water per one part of sludge system and allowed to settle. In this way the soluble alkalinity was "washed" from the surface of the suspended solids. Table 2 shows the effect of a high molecular weight cationic polymer in this operation. The elutriate suspended solids dropped sharply and the blanket suspended solids increased notably.

After the proper thickening and concentration operations have been completed, a synthetic organic polyelectrolyte may then be used to de-

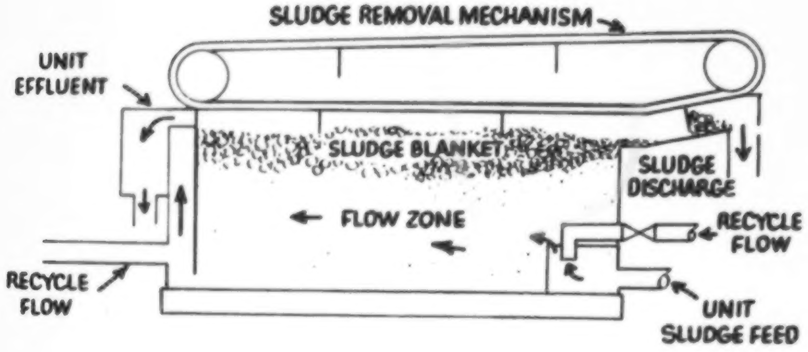

Figure 2: Solids Concentration Application

TABLE 1
Dissolved Air Flotation Activated Sludge

Treatment	*Influent suspended solids (ppm)*	*Subnatant suspended solids (ppm)*	*% Suspended solids removal*	*Float cake solids*
None	8,020	420	95	4.5
Synthetic organic polyelectrolyte	8,020	10	99.8	6.5

TABLE 2
Elutriation 50% — 50% Secondary Anaerobically Digested Sludge

Treatment	*Influent suspended solids (%)*	*Effluent suspended solids (%)*	*% Suspended solids removal*	*Blanket % suspended solids*
None	4.8	5,880	88	6.5
Synthetic organic polyelectrolyte	5.1	540	99	8.1

water biological sludges. A polyelectrolyte must attach itself to the surface of the suspended particle before flocculation can occur. However, in most cases, there is a shield of water molecules around the suspended particles. The synthetic polymer usually displaces water molecules every time it attaches itself to the surface of the particle. Thus, the number of polymer points of attachment often determine the water of hydration remaining on the floc particle. This basic mechanistic explanation partially explains why polyelectrolytes are effective as dewatering aids. However, a large percentage of the water associated with biomass sludge systems is within the organic cell membranes. Therefore, as the biological proportion of the system increases, the amount of "removable" water by normal dewatering techniques decreases. Also, these biological systems often have much larger hydration layers. Thus, the polyelectrolyte coats and percent cake moistures are usually directly proportional to the organic cell content. Table 3 shows the performance of a synthetic organic polyelectrolyte in a variety of real vacuum filtration systems. This data indicates that as the proportion of biological matter increases in the suspended solids system, (1) the percent influent sludge solids decreases, (2) the polyelectrolyte cost

TABLE 3
Results with Various Types of Sludge

Type sludge	*% Sludge solids*	*Conditioner cost $/ton*	*Filter yield lbs/ft²/hr*	*Cake moisture %*
Raw and digested primary	14	0.35	11.6	69
Digested primary	9.6	2.90	7.6	70
Digested primary and trickling filter	6.5	3.08	7.1	78
Digested primary and waste activated	7.0	5.40	6.0	80
Waste activated	5.5	7.95	4.0	85

TABLE 4
Vacuum Filtration — Coil Filter Elutriated Digested Mixture of Primary & Waste Activated Sludge

Sludge solids (%)	*Sludge conditioner Used*	*Chemical cost ($/ton)*	*Filter prod. rate psf/hr.*	*Cake moisture (%)*
7	$FeCl_3$ and Lime	6.25	5	80
7	Cationic polyelectrolytes	5.40	6	80

increases, (3) the filter yield decreases, (4) the percent cake moisture increases.

Many methods exist today to dewater biological sludges. These methods include drying beds, vacuum filtration facilities, filter presses, and centrifuges. Although recent work with polymers show them to be useful in all of these systems, drying beds do not always require chemical dewatering aids. However, the drying bed technique is losing favor with many municipal and federal organizations;[10] they require too much land, they evaporate too slowly; they cause odor problems; and they are too susceptible to the vagaries of weather. Also, this is not a satisfactory method to dewater biomass solids prior to sludge incineration.

Various types of vacuum filters are available to dewater biological sludge systems. The most common are the belt filter and the coil filter. Historically, inorganic coagulant chemicals have been used to condition biological sludge systems prior to vacuum filtration operations.[11,12] Trivalent acidic salts (such as ferric chloride) with or without lime was the only system used for many years in vacuum filtration operations. However, since the mid 1950's, synthetic organic polyelectrolytes have received increased acceptance in these applications.[13] Some of the advantages of a polyelectrolyte over those of inorganic materials are that the polyelectrolyte is not toxic, is less corrosive to personnel and equipment, does not build up on equipment surfaces (as with lime), and requires less handling. Many large plants now use polymers to dewater biological sludge systems.[14] In Table 4 the operating data of a typical coil vacuum filter is shown. In this case, the polyelectrolyte was less expensive, gave higher production rates (lbs/ft^2/hr), and gave similar cake moistures.

As mentioned previously, as the biological content of the biomass sludge system increases, the retained moisture tends to increase, the suspended solids density decreases, and the shear stability of the agglomerated suspended solids decreases. The decreased density and the poor shear stability characteristics of biomass sludges makes centrifugation techniques useful in many sludge dewatering applications.[15] The next figure (Table 5) shows typical operational data of a centrifuge dewatering a biomass sludge system. The most dramatic operational improvement may be seen in the centrate solids figures.

The use of cationic polyelectrolytes to concentrate and dewater biologically activated

TABLE 5
Centrifugation Waste Activated Sludge

Treatment	*Sludge influent suspended solids (%)*	*Centrate suspended solids (ppm)*	*Cake suspended solids (%)*
None	2.26	12,800	5.2
Cationic polyelectrolyte	1.66	78	8.2

sludge systems is now fairly well known. The particular type of cationic polyelectrolyte required to aid a given sedimentation or flotation operation is a function of the make up of the sludge system involved. The surest method of determining the optimum polyelectrolyte for a given system is to carry out bench scale or pilot tests. Sludge systems with high biomass contents require particular care in selecting the proper polyelectrolyte.

Many of the above remarks are equally applicable in anaerobic digested sludge systems. However, the polyelectrolyte requirements in this type sludge system are not nearly as critical. Vacuum filters are particularly useful for dewatering anaerobic sludges. Vacuum filters and sludge sedimentation thickeners have also been successfully used to handle mixed biomass systems (i.e., anaerobically digested mixtures of primary and secondary solids); but one may expect decreased production, higher moisture content, and increased shear stability problems as the content of the secondary solids in the system increases.

Properly concentrated and dewatered biomass material may greatly improve subsequent incinerator operations. However, these concentrated systems generally have higher BTU content and moisture contents (in weight/unit volume of sludge) than observed in other more inorganic solids systems commonly incinerated. Thus, temperature and draft control manipulations are often necessary to optimize incinerator operations. If the biomass sludge streams are not properly concentrated and dewatered, they may cause severe operational problems in incineration units.

Reasonable biomass solids concentration and dewatering techniques greatly improve both the economic and the handling characteristics of these systems in industrial full-scale plant operations. Where the above discussion may offer some guideline in the proper chemical treatments, only on site indepth studies will ultimately determine the proper chemical parameters in a given biomass sludge system. Further indepth comments concerning biomass sludge systems are available from a variety of authoritative sources and should be carefully consulted before laboratory or pilot tests are attempted.

REFERENCES

1. Dick, Richard I., "Fundamental Aspects of Sedimentation/1," p. 47-50, *Water and Waste Engineering*, February, 1969.

2. Dick, Richard I., "Fundamental Aspects of Sedimentation/2," p. 44-46, *Water and Waste Engineering*, March, 1969.

3. Teot, Arthur S., and Daniels, Stacy L., "Symposium on Colloid and Surface Chemistry in Air and Water Pollution," *Environmental Science and Technology*, p. 825-829, Volume 3, No. 9, September, 1969.

4. Priesing, C. E., "The Theory of Coagulation Useful for Design," *Industrial and Engineering Chemistry*, p. 38-45, Volume 54, No. 8, August, 1962.

5. Shyluk, W. P., *Journal of Polymer Science*, 2A, 2191 (1964).

6. Conway, R. A., and Kifer, L. D., "Polymeric Coagulant Improve Flotation Thickening," *Water Works and Waste Engineering*, p. 67-68, April, 1965.

7. Genter, A. L., *Elutriation*.

8. University of Michigan School of Public Health, *Sludge Concentration, Filtration and Incineration*, 1964.

9. Dalsstrom, D. A., and Cornell., C. F., *Economic Advantages by Improved Sludge Conditioning & Vacuum Filtration*, for presentation at the *Second Waste Treatment Conference Solids Handling & Anaerobic Digesting*, Manhattan College, New York, New York, April 24-26, 1957.

10. U. S. Department of the Interior, Federal Water Pollution Control Administration, *A Study of Sludge Handling & Disposal*, Publication WP-20-4.

11. Gail, R. S., and Bakerville, R. C., "Polyelectrolytes in the Filtration of Sewage Sludges," *Proceedings of the Filtration Society*, p. 37-52, January/February, 1970.

12. Thorpe, G. M., "Polyelectrolytes Help Water Pollution Control," *Hercules Chemist*, No. 55, p. 13-20.

13. Townsend, J. R., "What the Waste Water Plant Engineer Should Know About Centrifuges/2," *Water and Waste Engineering*, December, 1969.

14. Dahlstrom, Dr. Don, "Sludge Dewatering," *Chemical Engineering*, October 14, 1968, p. 103-107.

15. "Sludge Dewatering," Water Pollution Control Federation Manual of Practice, No. 20, 1969, p. 83-100.

Pressure Cooking of Excess Activated Sludge

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Cooking of excessive activated sludge as an art leaves something to be desired, but the practice involving the Porteous Process has a significant history in England, dating back to the mid-1930's. When excess activated sludge is pressure cooked under suitable conditions, the residual solids are more readily dewatered. Suitable conditions involve pressures in the order of 100 to 300 psig with the corresponding steam temperatures of 325 to 420°F.

The Porteous System, which in most of its applications has involved the direct heating of sludge with steam, is marketed in the United States by BSP Corporation. The Farrer Process, which utilizes the indirect heating of sludge in a pipe reactor, is marketed by Dorr-Oliver, Inc.

ROY F. WESTON has, for experience and for the potential application to problems, examined cooking of sludge as one technique that might be applied to difficult dewatering problems. Cooking pressures have ranged from atmospheric to 300 psig with corresponding steam temperatures. Most of the results have been obtained in small indirectly heated reactors with a few larger-scaled trials. The generalized observations are:

1. Cooking at pressures of less than approximately 100 psig (with corresponding steam temperature) does not improve the dewatering characteristics of the sludge.
2. At 100 psig, better results are obtained generally with indirect application of heat rather than direct heating with steam. Comments by others suggest that at 300 psig, results are similar with both indirect and direct heating.
3. At 100 psig, sludge which has been maintained aerobic will have better dewatering characteristics after pressure cooking, and
4. The primary change in a pressure cooked sample of excess activated sludge is the solubilization or organic material.

Data presented in this paper were obtained in a small-scaled reactor where one to two liters of excess activated sludge held in a glass container was placed in the reactor. Waste was placed in the bottom of the reactor. Heat was applied to the reactor externally. The reactor was steam purged before it was finally closed. Heat-up time for the reactor was twenty to thirty minutes and cool-down time was approximately the same. The time indicated in the data represents the time period at the indicated cooking pressure.

Solubilization of Material

Excess Activated Sludge from Domestic Sewage

Table 1 presents results from pressure cooking of excess activated sludge from the treatment of domestic sewage. The data do not

TABLE 1
Pressure Cooked Excess Activated Sludge from Domestic Sewage

Cooking Pressure psig	*Cooking Time min.*	*Initial VSS mg/L*	*Δ VSS mg/L*	*Δ COD mg/L*	$\frac{\Delta COD}{\Delta VSS}$
300	60	2830	2570	2692	1.04
300	60	5200	3250	4679	1.44
300	30	5880	5105	4587	0.90
300	15	5500	2630	3408	1.29
250	60	5200	2280	4579	2.00
250	30	4710	3130	4102	1.31
250	30	8050	6560	4810	0.73
150	60	6950	6015	5248	0.85
100	60	5880	2600	4217	1.62
100	30	8050	5280	3650	0.69

show strong correlations; but, in general, the decrease in volatile suspended solids is greatest at higher cooking pressures and cooking times. The range in the decrease of volatile suspended solids for the runs tabulated is forty to ninety percent. Most of the decrease in volatile suspended solids appears as an increase in the COD of the supernatant.

The ratio of the increase in COD to the decrease in volatile suspended solids as shown in Table 1 does not show a meaningful correlation to cooking times and temperatures as might be anticipated. If the decrease in solids is considered to be the result of hydrolysis of biological material, a relatively consistent ratio should result. In Figure 1, a relationship is suggested where the change in COD per unit decrease in volatile suspended solids becomes less as the initial concentration of volatile suspended solids is increased. If this correlation has merit, it suggests that something other than hydrolysis to soluble products is involved as the solids disappear. Dissolved oxygen is not present to an extent which would permit a significant amount of oxidation. Chemical degradation to produce volatile components might be a possibility, but materials in the off-gas from the reactor were not included in the balance.

The relatively consistent COD value in the supernatant (Table 1) appears to be independent of initial suspended solids or the reduction in suspended solids and suggests that some form of equilibrium is involved. If so, the equilibrium would be with materials in the gas phase of the reactor, and the question remains to be answered.

Excess Activated Sludge from Industrial Wastewater

Results from pressure cooking of excess activated sludge from the treatment of an industrial wastewater are presented in Table 2. The disappearance of suspended solids is in the range of fifty to eighty-five percent. The increase in COD of the supernatant shows an uncorrelated pattern and a wide ratio with change in suspended solids.

A condition not stated in Table 2 is that the runs are in order down the table (one sludge sample for the first four runs); and, consequently, the period of time that the sludge had been held prior to cooking increases down the table. The increasing ratio COD to suspended solids down the table suggests that the results of pressure cooking are significantly related to the condition of the sludge (aerobic, anaerobic, etc.) before it is cooked.

Dewatering Characteristics

In Tables 3 and 4 the results of vacuum filtration are presented as the specific resistance devel-

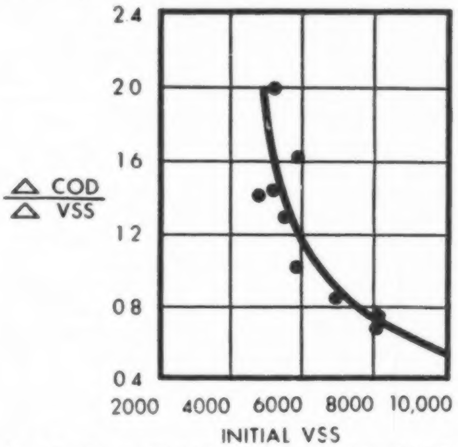

Figure 1: Pressure Cooked Excess Activated Sludge Solubilization of Material

TABLE 2
Pressure Cooked Excess Activated Sludge from Industrial Wastewater

Cooking Pressure psig	Cooking Time min.	Initial SS mg/L	Change SS mg/L	Change COD mg/L	$\frac{\Delta COD}{\Delta SS}$
250	30	19150	15470	5191	0.33
250	60	19150	16000	8740	0.54
150	60	19150	9730	8360	0.86
150	120	19150	11790	11960	1.01
250	60	20900	13100	19000	1.45
300	15	19760	12210	16400	1.34

TABLE 3
Pressure Cooked Excess Activated Sludge from Domestic Sewage Dewatering by Vacuum Filtration

Cooking Pressure psig	Cooking Time min.	Specific Resistance, sec²/gm		Cake Moisture %
		Raw Sludge $X\ 10^{-9}$	Cooked Sludge $X\ 10^{-9}$	
300	60	1.4	0.03	—
300	60	2.5	0.04	49
300	30	2.5	0.04	61
300	15	8.8	0 70	—
250	60	2.5	0.06	53
250	30	3.1	0.06	—
250	30	1.3	0.12	66
150	60	2.2	0.05	59
100	60	2.5	0.80	—
100	30	1.3	0.90	—

TABLE 4
Pressure Cooked Excess Activated Sludge from Industrial Wastewater Dewatering by Vacuum Filtration

Cooking Pressure psig	Cooking Time min.	Specific Resistance, sec²/gm		Cake Moisture %
		Raw Sludge $X\ 10^{-9}$	Cooked Sludge $X\ 10^{-9}$	
250	30	14	2.95	—
250	60	14	0.38	69
150	60	14	0.84	83
150	120	14	0.81	83
250	60	5.5	0.46	77
300	15	5.8	0.43	76

oped by the cake in bench-scaled vacuum filtration evaluation. As a guide in reading the results, a specific resistance of approximately 0.3 to 0.4 × 10^9 sec²/gm represents a sludge that is filterable, but with moderate difficulty. Lower specific resistance numbers represent more easily dewatered sludges.

The dewatering characteristics of pressure-cooked excess activated sludge from domestic sewage are presented in Table 3. The raw sludge without conditioning in any manner essentially could not be filtered. With successful pressure cooking the specific resistance decreased by a factor of approximately fifty, and dewatering was accomplished readily. Pressure cooking was unsuccessful at 100 psig and at 300 psig for 15 minutes. Pressure cooking for 30 and 60 minutes and 250 and 300 psig and for 60 minutes at 150 psig was successful.

Cake moisture was in the range of 50 to 60 percent compared to the normal 70 to 80 percent for chemically conditioned sludge. The one cake moisture of 66 percent was the result of partially successful pressure cooking. The nature of the cakes was such that further dewatering could be accomplished by pressing the cake.

The dewatering results in Table 4 for pressure-cooked excess activated sludge from industrial wastewater do not show the same success as developed with the domestic sewage sludge. The raw sludge had a very high specific resistance and could not be dewatered by vacuum filtration. Pressure cooking decreased the specific resistance by a factor of ten to twenty and the resulting sludge could be filtered with moderate difficulty. Cooking at 300 psig for 15 minutes, which had not been successful for the sludge from domestic sewage, was successful for the industrial wastewater sludge.

Cake moisture was not good and ranged from 70 to 85 percent. The cake was not as strong structurally as that from domestic sewage sludge, and further dewatering by pressing would be less practical.

Biodegradability of Organic Material in the Supernatant

The supernatant from the dewatering of pressure cooked excess activated sludge is a strong wastewater and must be returned to the treatment process. The biodegradability of the supernatant is characterized in Tables 5 and 6. The logical anticipation is that hydrolyzed products from pressure cooking of excess activated sludge will be readily available to microorganisms as a source of energy and synthesizable material. The results do not confirm the anticipation. The best criteria for evaluation of the biodegradability is the ratio of ultimate carbonaceous BOD to COD. For compounds that are readily utilized in the biological system, the ultimate carbonaceous BOD is about 75 to 80 percent of the COD.

BOD and COD values for supernatant from pressure-cooked excess activated sludge from domestic sewage are compared in Table 5. The BOD$_5$ values are 60 to 80 percent of the ultimate carbonaceous values, which demonstrates that the materials which are utilized biologically are readily available. The ratio of ultimate carbonaceous BOD to COD is in the range of 40 to 60 percent rather than the anticipated 75 to 80 percent and shows that about 40 percent of the organic material present is resistant to biological oxidation.

TABLE 5
Pressure Cooked Excess Activated Sludge from Domestic Sewage
Biodegradability of Supernatant

COD mg/L	BOD 5-day mg/L	BOD Ultimate mg/L	BOD_{ULT}/COD
4960	1420	1955	0.40
5357	1740	2740	0.51
4410	1650	2700	0.61
7776	2310	3300	0.43
5540	2250	3100	0.56
5807	2280	3180	0.55
6188	2100	3000	0.49
6060	1470	2600	0.43
6000	2310	2950	0.49
4800	2220	2750	0.59

TABLE 6
Pressure Cooked Excess Activated Sludge from Industrial Wastewater
Biodegradability of Supernatant

COD mg/L	BOD 5-day mg/L	BOD Ultimate mg/L	BOD_{ULT}/COD
7,390	2100	—	—
10,940	1830	—	—
10,560	840	—	—
14,160	1380	—	—
21,200	2190	6500	0.31
18,600	3360	5500	0.30

The net result of resistance to biodegradability is to decrease the impact of recycled supernatant to an approximate 25 percent increase in load on the biological system from what would otherwise be approximately a 30 percent increase in load. The pounds of COD in the treatment plant effluent would be increased by 10 to 15 percent due to the resistant material.

In Table 6, COD and BOD values for supernatant from pressure-cooked activated sludge from industrial wastewater present a different story. The biodegradability of organic materials in the supernatant is poor as shown by an ultimate carbonaceous BOD to COD ratio of 30 percent. Thus, the impact of recycled supernatant on the biological oxidation system is minimized in this case, and the pounds of biologically refractory material in the treatment plant effluent are increased.

CONCLUSIONS

1. Pressure cooking of excess activated sludge conditions the residual solids to achieve a 20 to 50-fold improvement in the dewatering characteristics as indicated by the specific resistance of cakes developed during vacuum filtration.

2. Fifty to ninety percent of the volatile suspended solids in the sample before cooking may disappear during pressure cooking.

3. The disappearance of volatile suspended solids was not quantitative offset by the increase in COD of the supernatant, although most of the solids lost appear as soluble COD.

4. As much as fifty percent or more of the organic materials in the supernatant are resistant to biological degradation.

5. The economic justification of pressure cooking for sludge conditioning must recognize the approximate twenty-five percent impact on organic loading to the biological oxidation process.

6. Limited evidence suggests that the condition and the handling of sludge prior to cooking has a significant effect on the success of the cooking operation and the COD in the supernatant.

Biodegradation of Concentrated Aqueous Solid Wastes – Aerobic Versus Anaerobic Systems

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The disposal of concentrated solid organic wastes has become one of the major waste disposal problems of our times. It has always been the major factor in domestic sewage treatment; but it has never received the attention that the other treatment processes have received. During the past decade considerable attention has been focused along two lines, a better understanding of the biochemistry of anaerobic digestion, and the development of polyelectrolytes to assist in improved filtration. One of the newest problems related to concentrated organic wastes is that of manure disposal from confined animal operations. This problem has been attacked from both an aerobic and an anaerobic viewpoint. Both methods have distinct advantages and disadvantages.

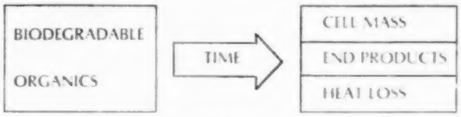
Increased interest in refuse disposal has prompted closer examination of both aerobic and anaerobic biological processes for treatment. The results to date have been so scattered that little specific data are available, but they do look promising. One of the most challenging problems which seems to be developing is related to the disposal of all of the waste activated sludge being generated in highly efficient treatment plants. In small units aerobic digestion is reasonably effective, but other methods must be used for larger units. The complexity of the solids handling problem has created some confusion and has caused some concern as to the effectiveness of biological treatment as compared to chemical and physical treatment. There is nothing magical about biological treatment. It is not the answer in all cases, but it is the most efficient system in many cases. The objective of this paper will be to review the fundamentals of biological treatment as related to concentrated solid organic wastes and to set forth design criteria used in operating systems where possible.

Fundamental Concepts

The biological stabilization of organic wastes is carried out by simple microbial metabolism over a definite period of time in a controlled environment. Solid wastes pose a definite metabolic problem, contact between the microorganisms and the biodegradable portion of the solid waste. Few solid wastes are entirely all organic and even less are all biodegradable. In aerobic systems, i.e., those with excess dissolved oxygen in all parts of the system at all times, bacteria and fungi form the microbes responsible for primary metabolism of the solid wastes. Protozoa and rotifers form the microbes responsible for secondary metabolism, feeding on the bacteria, fungi, and the solid wastes. In anaerobic systems the bacteria are the important microbes.

Since direct contact between the wastes and the microbes is critical, the wastes should be macerated to present the maximum surface area to volume ratio desirable for the particular environment. In an aqueous environment the solid wastes are broken as small as possible. In a non-aqueous environment there must be a large enough particle size to permit air to pass around the particles. Smaller particles are permissible if more rapid mixing is employed. Mixing is important in determining the rate of metabolism until there is adequate contact between all the incoming wastes and the microbes responsible for metabolism. Mixing is more important in high rate systems than in low rate systems. By and large there have not been enough studies correlating the rate of metabolism with the degree of mixing.

The basic metabolic reaction results in the transfer of a portion of the biodegradable organics into new cell mass with a definite portion being transferred to stable materials at a lower energy level. The energy change in the metabolism of the organic matter increases for that portion converted to microbial cells and decreases for that portion converted to stable end products. Needless to say there is a balance between the energy converted to cells, the energy released by the production of lower energy compounds, and the energy lost as heat by all of the many reactions.



The non-biodegradable organics remain untouched by the microorganisms and must be considered as inert. One will recognize that some organic compounds are biodegradable, but only very slowly under the environment being used. Such compounds should be treated as being non-biodegradable since they will react in the same fashion as non-biodegradable compounds in practical treatment.

Actually, the non-biodegradable organics and the inorganic suspended solids have the greatest effect on the design and the operation of waste treatment systems handling concentrated solid wastes. These inert solids tend to fill the reaction vessel with inert materials which do not contribute to the metabolic reactions. But it should be recognized that a definite fraction of these inert solids are needed to help rapid microbial solids separation in gravity sedimentation units. Solids concentration and separation from the liquid pose the major problem in the treatment of concentrated solid wastes.

The environment plays an important part in determining the microbes which can grow, their rate of growth, and the metabolic patterns which can be used. It is impossible to discuss these topics in detail in a single paper as they are much too complex. A few general principles will be stated at the risk of being accused of presenting too simplified an approach for the die-hard theorists.

Aerobic-Anaerobic Environments

The aerobic reaction requires an excess of oxygen at all times and permits the microbial enzymes to obtain the maximum energy yield from a unit of organic matter. The oxidation reactions within the bacteria and the fungi will convert the carbon in the energy fraction to carbon dioxide, the hydrogen to water, the excess nitrogen to ammonia, the excess sulfur to sulfates, and the excess phosphorus to phosphates. All materials capable of undergoing oxidation that do not become cell mass are converted to the oxidized state. The excess ammonia released from metabolism of the complex organic solids will be oxidized to nitrites and nitrates provided the autotrophic, nitrifying bacteria are present.

The net effect of the aerobic reactions yielding maximum energy is for maximum solids to be produced per unit of organic matter metabolized. With a mixed organic substrate such as domestic sewage, approximately 2/3 of the substrate will be converted to microbial cells while the remaining 1/3 is oxidized to stable end products. It must be recognized that the chemical nature of the substrate can affect this yield. All carbohydrate materials will produce greater cell mass yields per unit of material metabolized. Proteins and fatty acids will produce lower cell mass yields. This substrate effect is bound to microbial predomination. It has been shown that fungi will produce more cell mass from a unit of carbohydrate than will bacteria. Thus it is important that microscopic examinations be a part of any fundamental metabolic studies. This has been almost totally neglected until recently.

The anaerobic environment requires a different form of oxygen than dissolved oxygen. Nitrates, nitrites, sulfates, carbon dioxide, and organic matter can act as electron acceptors in a similar manner as dissolved oxygen, but with different end products. Nitrates and nitrites will be reduced in proportion to the extent of reduction required. If excess organic matter is present, the reaction will proceed to nitrogen gas, carbon dioxide, water, and ammonia. The ammonia is produced from the organic matter and not from the nitrates.

$$\text{Organic matter} + \text{nitrates} + \text{cells} \xrightarrow{\text{time}} \text{more cells} + N_2 + CO_2 + H_2O + NH_3$$

This reaction is termed "dentrification" and is a very common reaction in nature.

Sulfates are reduced by a special group of bacteria known as *Desulfovibrio*. In the presence of organic matter the sulfates are reduced to a number of reduced states of which hydrogen sulfide is the lowest.

$$\text{Organic matter} + \text{sulfates} + \text{cells} \xrightarrow{\text{time}} \text{more cells} + H_2S + CO_2 + H_2O + NH_3$$

Since hydrogen sulfide is not too soluble in water, it can create a major odor nuisance problem. Loss of hydrogen sulfide will be dependent upon the pH of the system or its iron content. Iron reacts readily with hydrogen sulfide and forms an insoluble precipitate. It may or may not form an additional problem.

Carbon dioxide is metabolized by the methane bacteria to form methane and water and acetic acid.

$$\text{Organic matter} + \text{carbon dioxide} + \text{cells} \xrightarrow{\text{time}} \text{more cells} + CH_4 + H_2O + NH_3 + \text{acetic acid}$$

The acetic acid is produced as a result of the partial degradation of the complex organic solids. The methane bacteria can oxidize it further to methane and carbon dioxide.

$$\text{Acetic acid} + \text{cells} + NH_3 \xrightarrow{\text{time}} \text{more cells} + CH_4 + CO_2$$

By and large, organic matter is degraded anaerobically to yield organic acids, aldehydes, ketones, alcohols, carbon dioxide, water, and ammonia depending upon how much hydrogen acceptor is readily available. The end products accumulate on the basis of maximum possible energy yield between the initial material and the final products. One should recognize that this rearrangement of atoms yields some small amount of energy but does not change the oxygen demand significantly. The methane bacteria are able to carry out further metabolism of the end products to methane and carbon dioxide. The effective use of anaerobic metabolism normally requires the balance in the bacteria which attack the organic matter and the methane bacteria.

Anaerobic metabolism yields approximately 1/10 the energy of aerobic metabolism. The net result is that more organic matter must be metabolized anaerobically to produce a unit of cell mass. This is the real advantage of anaerobic processes. The metabolic reactions produce few solids and lots of methane, carbon dioxide, and water. Since methane is poorly soluble in water, it is lost to the atmosphere, leaving a relatively low organic effluent after treatment.

pH

The good growth of microbes requires an environment which is buffered at an optimum pH range. Normally, bicarbonate buffer is used to hold the pH between 4.5 and 9.5. Aerobic bacteria tend to grow best between pH 6.5 and 8.5; while fungi will overgrow bacteria as the pH approaches 4.5. Anaerobic systems will operate over a wide pH range for all microbes but the methane bacteria. They grow best in the pH range 6.5-7.0 which is a very narrow pH range.

As the pH rises above 8.0, it is possible to lose nitrogen from biological systems as ammonia. This is seen most often in aerobic systems which employ lots of agitation. Anaerobic systems tend to exhibit an ammonia toxicity to the methane bacteria and are detrimental. Thus it is that pH is one of the most critical environmental factors affecting biological metabolism in field systems.

Temperature

Temperature affects the rate of metabolic reactions by doubling the rate for every 10°C temperature increase from approximately 5°C to 35°C. Below 5°C the rate of metabolism falls off sharply, reaching zero when the water in and around the microbes freezes. It is possible to operate low temperature systems at high rates merely by raising the population of active microbes.

Above 35°C the common bacteria begin to undergo denaturation of their enzymes. The net result is death of the bacteria around 42°C. Fortunately, there are thermophilic bacteria and fungi which can grow at temperatures up to 65°C before enzyme denaturation starts.

There are many other environmental factors of importance such as mixing and reaction time. Since these factors are so intimately involved with the microbial population and the solid waste concentration, no effort will be made to discuss these fundamentals separately but rather will be incorporated as part of the discussion of specific waste treatment systems.

Waste Characteristics

In order to understand the biological treatment of concentrated solid wastes one must have a real understanding of the waste characteristics. This is very true in evaluating treatment plant performances. Strangely enough, few people have made a real objective look at the characteristics of domestic sewage as affected by biotreatment. The BOD_5, the suspended solids (total and volatile), the settleable solids, the pH, the temperature, and a few other tidbits were considered adequate.

Few people realized that approximately 40 percent of the volatile suspended solids in normal domestic sewage were actually nonbiodegradable organics which would not undergo change either aerobically or anaerobically. These materials had to be handled and disposed of along with the inorganic solids. Recognition of this fact sooner would have changed evaluation of anaerobic digestion and extended aeration systems a lot sooner. It would have helped prevent numerous misunderstandings in interpretation of data over the years.

A normal domestic sewage would be expected to have 200 mg/l BOD_5 and 240 mg/l total suspended solids. With 50 mg/l inorganic suspended solids, the volatile suspended solids should contain around 70 mg/l non-biodegradable organic solids and 120 mg/l of biodegradable organic solids. These are important characteristics for further use. There are other important waste characteristics which will be mentioned later.

Animal manures contain non-biologically degradable fractions as well as biodegradable fractions. The nature of the feed determines the manure characteristics. Bedding material can also affect manure characteristics. Animals fed a high protein processed ration will produce a manure with entirely different characteristics than from animals fed fodder and rough grains. They cannot be treated in the same manner. Rumen animals will have a different manure than non-rumen animals. There is a real need to obtain better analyses of manures based on feed characteristics. All that enters the animal either appears as new tissue or is lost as waste products, most of which are urine and manure. Loss of retention of animal urine with the manure will have a very important effect on the significant waste. It is not surprising to see considerable variation in manure analysis. There will continue to be confusion until analyses are made on the basis of feed fed per day which compensates for the size of the animal. Because of the wide variations in manure analysis, it is not desirable to try to present a general analysis until more data are available.

Refuse is another solid waste which has not been well defined. The data on refuse characteristics are appalling to say the least. One thing is obvious, there is a real need for a study of refuse characteristics. Refuse consists largely of inert materials such as metals, glass, bricks, rubble, etc. Residential refuse and commercial refuse have more biodegradable materials and less inert materials. By separation of the residential refuse and commercial refuse from the construction refuse, the old automobiles, and other large refuse objects, it is possible to obtain a material with a relatively uniform characteristic.

Paper	50-60%	Metal	10-15%
Garbage	10-20%	Glass	10-15%
Grass	0-10%	Miscellaneous	0-5%
Tree trimmings	5-15%		

Of these materials, approximately 80 percent is subject to biological action. Garbage and grass react readily with microbes while paper and tree trimmings react slowly with microbes. Further research is necessary to determine the magnitude of the biodegradable fraction in view of increased use of home garbage grinders.

Anaerobic Digestion

Controlled anaerobic digestion has been used for years in the treatment of sewage solids. The dilute solids in raw sewage are concentrated from 240 mg/l to around 40,000 mg/l by gravity sedimentation. Thickness can increase the solid concentrations up to 60,000 or 70,000 mg/l. Only 60 percent of the volatile fraction are biodegradable. It is possible to use a completely mixed anaerobic digestion unit on a one pass system to stabilize all of the wastes in approximately 10 days at a temperature of 35°C. A two stage system will be needed since the solids will have to be concentrated and dewatered prior to discharge back to the soil.

It would be possible to shorten the reaction time if the microbial population could be increased. Unfortunately, recirculation of sludge results in excess accumulation of inert solids. It is more efficient to use a larger reaction vessel with a single pass operation than to recycle settled digested sludge through a smaller tank. Operational ease controls the design of most anaerobic digestion units.

Anaerobic digestion of sewage solids has long been considered an inefficient process since so many solids remained after treatment. Actually, anaerobic digestion is very efficient in reducing the biodegradable fraction of solid wastes providing good mixing, proper temperature, and adequate reaction time are provided.

Anaerobic digestion requires a satisfactory balance between the acid forming bacteria and the methane bacteria. The methane bacteria must be able to metabolize the organic acids as fast as they are produced. Thus the rate of solids feed becomes the most critical operational issue. Anaerobic digesters should be fed at as uniform a rate as possible to minimize upset. The most critical operation parameter is pH. It is important to develop a continuous recording pH system that can be used to determine the pH in the digesters under the high solids concentrations.

Excess activated sludge has posed a problem in anaerobic digesters for over 50 years. Excess activated sludge will not concentrate much beyond 10,000 mg/l except where there are lots of inert solids in the sludge. Thus excess activated sludge poses a high bulk, low mass problem when mixed with primary sludge. Since activated sludge happens to be living and dead microbes, non-biodegradable organics, and inorganics, there is very little material which will undergo digestion. About the only thing that will happen will be for the living bacteria to starve to death. The net result is that activated sludge occupies space but does not undergo digestion. It is apparent that excess activated sludge should be handled by some other process than anaerobic digestion.

Animal manure treatment by anaerobic digestion has had both success and failure. The treatment of the manure without urine had been reasonably successful but it has failed when urine is added. Fundamentals indicate the problem is one of ammonia toxicity to the methane bacteria. If other wastes are available to dilute the total effect of the urine, it is possible to treat animal manure by anaerobic digestion. The complexity of anaerobic digestion has not found favor with farmers and will not find extensive use.

The treatment of refuse by anaerobic digestion works but is limited by the large fraction of inert solids. The problem of adding dry solids to a liquid to obtain a small reduction in solids and then followed by complex dewatering is far greater than other solutions to the problem of refuse disposal.

Anaerobic Lagoons

Anaerobic lagoons are open anaerobic digestion units in deep earthen ponds. The lack of mixing and temperature control reduces the effectiveness of the anaerobic process, but the low cost and simplicity of operation has stimulated its development.

With domestic sewage solids, anaerobic lagoons have not proved very successful. The systems remove the BOD and the suspended solids but at the expense of a tremendous odor production. The lack of adequate buffer results in the production of volatile acids and amines that create excessive odor nuisances.

Anaerobic lagoons have proved most successful in treatment of beef cattle slaughterhouse wastes. The reasons for this success are due to a better buffer system, formation of a heavy grease scum, and continuous seeding with methane bacteria. The high protein content of slaughterhouse wastes yields a well buffered system, but the high use of wash water prevents ammonia toxicity. The inability to remove all of the grease from the wastes soon results in the formation of a heavy scum on the surface which acts as a lid and prevents loss of odorous materials. Odors are usually severe until the scum forms. Rumen animals have a high population of methane bacteria in their system so that their wastes contain a continuous seeding of the bacteria most easily affected by adverse environmental conditions.

The major problem with anaerobic lagoons is the loss of capacity due to settled solids. It is necessary to periodically remove excess solids onto the land or to abandon the lagoon when it fills with solids. It is also possible to produce such a low pH in the settled solids layer that all microbial activity ceases and the organic matter remains in a pickled state until agitated. It is going to be interesting to observe how many anaerobic lagoons function properly and how many are merely pickling the solids.

Oxidation Ditch

The oxidation ditch has recently found use in the treatment of confined animal wastes, hogs and beef cattle. The oxidation ditch system is both a waste collection system and a treatment system. It is possible to use a slotted floor over the oxidation ditch system. The manure falls into the ditch and is picked up by the flowing microbial mass and metabolized. With minimum water use systems the detention time in the oxidation ditch is approximately 30 days. The concentrated manure is diluted by the ditch contents to a level where it is rapidly metabolized. The microbial cells resulting from metabolism must be removed periodically and put on the land. The oxidation ditch is just beginning to demonstrate its value in handling concentrated wastes.

Aerobic Digestion

The oxidation ditch is just one form of aerobic digestion of concentrated solid wastes. It is possible to use other types of aeration systems provided adequate dilution is available to reduce the oxygen demand rate below the oxygen transfer rate in the tank. This usually means detention times of 15 to

30 days. Such long detention times are not economical except for small waste volumes. Fortunately, most concentrated wastes are low in volume. If the volume is high, aerobic digestion is not the best process to use.

Aerobic digestion has been best used for treating excess activated sludge. A 5-10 day aeration period will be sufficient to stabilize excess activated sludge. Normally, we use a series of tanks to permit maximum digestion. The aerobically digested solids can be dewatered the same as anaerobically digested solids. Aerobic digestion of excess activated sludge will result in more efficient use of anaerobic digestion equipment for primary sludge.

Sanitary Landfill

Refuse is generally buried in a sanitary landfill. Metabolism is limited and normally slow due to poor environmental conditions. The observed results have varied from rapid metabolism to no metabolism. The moisture level is very important in determining metabolism. By and large the metabolism is anaerobic since air cannot penetrate the landfill easily. It should be recognized that the sanitary landfill is a poor device for treating wastes. Fortunately, the amount of biodegradable wastes is limited.

Composting

In order to stabilize refuse prior to disposal, it is possible to compost the biodegradable fraction. In composting the inert materials are separated from the biodegradable materials. The biodegradable materials are ground to about one inch particle size and then the moisture is adjusted to approximately 60 percent. Aerobic bacteria and fungi will stabilize the organic matter in a short period of time. The composting process generally is a thermophilic process reaching temperatures in excess of 65°C. Composting has not been successful to date because of its complexity of operations.

Surface Stabilization

A modified composting process which may have value in refuse disposal is surface stabilization. The degradable fraction of refuse is ground and turned into the surface of the soil with a disc harrow. Water is added to stimulate microbial reactions. The resulting aerobic metabolism results in rapid stabilization of the refuse 30-45 days in the summer. The treated material becomes the base for the next layer of refuse. This permits the development of an almost inexhaustable refuse disposal site. The stabilized refuse can be removed and used as fill material or top dressing for poor soils.

Surface stabilization has merit for treating feedlot wastes. The addition of ground limestone to neutralize excess acids will permit the manure to be aerobically stabilized rapidly. The stable humus can be returned to the land without excessive nuisances. The problem with animal manure is to change its characteristics without the creation of nuisance conditions. Dilution and exposure to aerobic microbes will result in rapid conversion of manure to stable materials.

SUMMARY

There are a number of biological systems which can be used to treat concentrated solid wastes: anaerobic digestion; anaerobic lagoons; aerobic digestion; oxidation ditches; sanitary landfill; composting; and surface stabilization. Each has certain advantages and disadvantages. Only by understanding the waste characteristics, the fundamentals of biotreatment, and the desired degree of treatment can the proper system be selected and designed.

Microbiology In Solid Waste Processing

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The interaction of microorganisms in man's environment cannot be sufficiently emphasized. Micoorganisms play an important role in the biological conversion of organic wastes as the prime feeders in the long food chain that exists in nature. It is difficult to assess the several nonbiological processes which facilitate the natural microbial decomposition of waste materials. There are many processes which are nonbiological in character, that occur in nature. Photochemical and surface oxidations are common, and heavy metals take part in such reactions as catalysts. These abiotic reactions help to increase the effeciency of transformation of organic materials into biomass by microorganisms. The accumulation of organic solid wastes in our environment, leading to its rapid deterioration, is brought upon by several causes. One of the main reasons seems to be the generation of a large amount of materials in a short period of time, which are either only slowly degradable or not degradable at all by microflora alone. Agriculture by its very nature produces great amounts of waste materials. To cite an example, in the canning industry enormous quantities of inedible plant tissues must be grown and discarded in order to produce the desired amounts of fruits and vegetables. The tonnage of raw materials sent to the processor forms only a minor percent of the tonnage of stalks and vines left in the field. The outpouring of by-products of industrialization to satisfy the needs and comforts of men has resulted in upsetting the balanced ecological cycle. It has become necessary that the advanced technology of the present day has to be directed to simulate the biotic and abiotic reactions in nature to recycle the wastes efficiently into our economy. Thereby, we will be able to arrest the runaway phenomenon and restore the equilibrium or the steady-state so that man may be in continuous balance with the environment.

There are several methods of disposal of organic wastes known to man at present, but many of these are highly inefficient and of questionable value. Two of the well-known methods of disposal are landfills and composting. Another process of disposal which has been under development for some time makes use of the application of the technology of fermentation to yield a product which is highly nutritive as animal feed.

Let us now consider some of the microbiological aspects of landfills and composting. Some of the data obtained from investigations on the ecology of soil microflora may be successfully applied to studies on landfills. The regularity of

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microbial distribution is determined not only by environmental factors such as temperature, light, humidity, aeration, but also by the structure and composition of the soil. Contrary to the general assumption, the microbial cells are not uniformly distributed in the soil.[1] The distribution of microorganisms is not diffuse but focal. In each focus, large or small, cells of one species or several nonantagonistic species grow and concentrate. The rate of growth and mobility of microorganisms differ greatly from species to species and they also vary in relation to the properties of the soil. Furthermore, the type and state of the soil determines the number and size of the foci or individual concentration of the microbes. The microorganisms do not move through small pores of natural and artificial substrates mechanically but they move as a result of growth. The greater the rate of growth, the more rapidly they pass through such pores and capillaries.

Studies in the laboratory have to be carried out on the nature of the soil and the type of microflora present at the site to be used for landfills. Also, it would be advantageous to obtain information about the microorganisms which could establish themselves in the organic waste to be disposed of. In certain cases, it becomes a necessity to seed the landfills with proper organisms, since otherwise, due to lack of competition, pathogenic organisms may multiply and the landfill may become a public health hazard. During seeding operations it has to be borne in mind that the microorganisms do not possess the same ability to establish ecological niches in different soils and environments. Hagen et al.[3] conducted an experiment to study the liability and growth of different organisms in three different soils, and their results are illustrated in Table 1.

A second approach to the experimentation on landfills is the application of the methodology of investigations on the ecology of bacteria beds in the treatment of waste water.[5] The main paths of material transfer in bacteria beds are diagrammatically represented in Figure 1. The bacteria beds bear the same relationship to landfills as a continuous cultivation of microorganisms to batch cultures. In both processes of waste disposal, the important biotic factor that affects the balance of populations is the basic food supply, namely the organic waste. More information will be necessary on the effect of different environmental factors as well as pretreatment of wastes on the accumulation of bacterial films before landfills may be used efficiently as a method of recycling the wastes into the soil.

TABLE 1*
Viability and Growth of Microorganisms on Different Soils

		Textural Classification		
Organisms	*# inoculated*	*Brunizemic Soil (silt loam)*	*Desertic (clay)*	*Podzolic (salt loam)*
Bacillus cereus	10^4	+	-	+
	10^3	+	-	+
	10^2	+	0	+
PA 3679	10^4	-	0	-
	10^3	-	0	-
	10^2	0	0	-
Lactobacillus plantarum	10^5	0	-	0
	10^4	+	-	+
	10^3	+	-	+
Pseudomonas aeruginosa	10^4	+	-	+
	10^3	+	-	-
	10^2	+	-	-
Staphylococcus aureus	10^5	+	-	+
	10^4	+	-	+
	10^3	+	-	+
Staphylococcus albus	10^5	+	-	+
	10^4	+	-	+
	10^3	+	-	+

+ increase
- decrease
0 no change in the viability
* adapted from Table II of Reference 3.

Studies on composting have received a good deal of attention, and conditions for efficient conversion of cellulosic wastes into compost have been recorded. But the cost of transportation of wastes to composting plants as well as the availability in the market of cheaper soil conditioners make the process uneconomical and unattractive as a method of waste disposal.

Utilization of wastes as substrates for microbial fermentation may develop into a profitable secondary industry. The efficiency and success of such an operation depends upon a knowledge of several factors. First, the organisms possessing the necessary physiological function for the breakdown of a specific organic waste have to be isolated by enrichment techniques. Methods of different pretreatments need to be looked into to obtain rapid growth of cells. In preference to batch processes, continuous processes may be advantageously studied, for they possess the inherent capability of maximum productivity with possibilities of automation. The technology has to be optimized to obtain maximum rate of conversion as well as the maximum yield of products. In certain instances, it may be necessary to make use of more than one organism to operate the process economically. Very little information is available about the nature of interaction of microorganisms in continuous culture. Bungay and his collaborators have been investigating the oscillations in populations of mutualistic interactions.[2] More emphasis has to be placed on studies on the interrelationship of population dynamics of different organisms with the productivity of biomass. Such an experimentation will eventually lead to a better understanding of the basic mechanisms in the microbial ecology of the system and thereby standardizing the output. We have been investigating for some time to develop a method of fermentation of cellulosic wastes to obtain single-cell proteins. "Single Cell Proteins" is a term introduced by the investigators at MIT to denote food protein from microorganisms. About 50 percent of the weight of the microorganisms in general is composed of protein. The organisms use the nutrient source not only for synthesizing protoplasmic material but also for the energy required for such syntheses. The proportion of nutrients converted into cell mass depends to a large extent on the nature of the organic substrate (Table 2).[6]

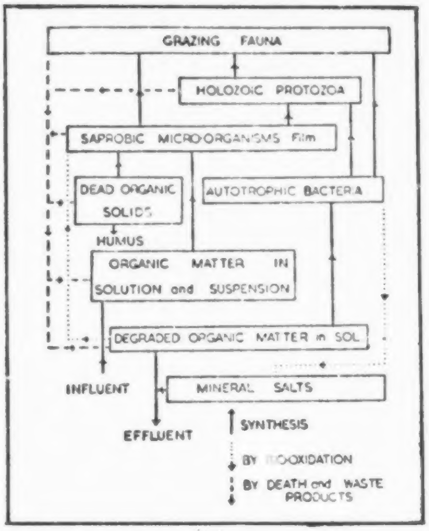

Figure 1: Schematic Representation of the Main Paths of Material Transfer in the Purification of Organic Wastes in Bacteria Beds (5)

TABLE 2
Cell Yields of Cultures of Candida on Various Substrates

Organism	*Substrate*	*Cell yield g/g* *Substrate*	*Cell yield g/g* *Substrate Carbon*
C. utilis	Glucose	0.51	1.28
C. utilis	Acetic acid	0.36	0.90
C. utilis	Ethanol	0.68	1.30
C. intermedia	n-alkanes (C_{14}-C_{18})	0.80	0.94
C. intermedia	n-alkanes (C_{16}-C_{22})	0.81	0.96
Candida sp.	Octadecane	0.74	0.87

Since we are mainly interested in cellulolytic organisms as single cell proteins, our choice of microbes was restricted to a selection of bacteria or yeast. Our search for organisms capable of utilizing bagasse as substrates led us to screen for cellulolytic bacteria in rotting sugarcane stalks as well as the soil from sugarcane fields during the harvesting season. The usual method of "elective technique" was used to enrich for cellulolytic bacteria. Plating methods were used for the isolation of single colonies. Relatively pure cultures of cellulolytic bacteria were obtained by these procedures. However, it was noticed on careful examination of their cellulolytic activity, the isolates were always associated with some other species of bacteria on the solid media. Hence, a more stringent selection of a single clone of bacteria by the method of terminal dilution was carried out, and the isolated clone was identified by the diagnostic tests according to the Manual of Microbiological Methods.

The isolated strain of cellulolytic bacterium is a gram negative rod, 0.8-1.2 μ in length and 0.3-0.5 μ in diameter. It is catalase positive and hydrolyzes gelatin slowly. The morphological and cultural characteristics of the isolate were comparable to the description of the genus *Cellulomonas* in Bergey's Manual of Determinative Bacteriology.[4]

Figure 2 represents the kinetics of growth, and the excretion of cellulase in the medium. It is apparent from Figure 2 that the activity of the enzyme in the menstruum increased sharply at the early stationary phase of growth. Since the organism is capable of hydrolyzing cellulose even during the logarithmic phase of growth, it is reasonable to assume that the enzyme is intramurally located and is released into the medium due to certain transformations in the structure of the cell wall of the organisms at the end of the logarithmic phase.

Investigations on the growth of this organism under different environmental conditions showed that the organism was able to grow well be-

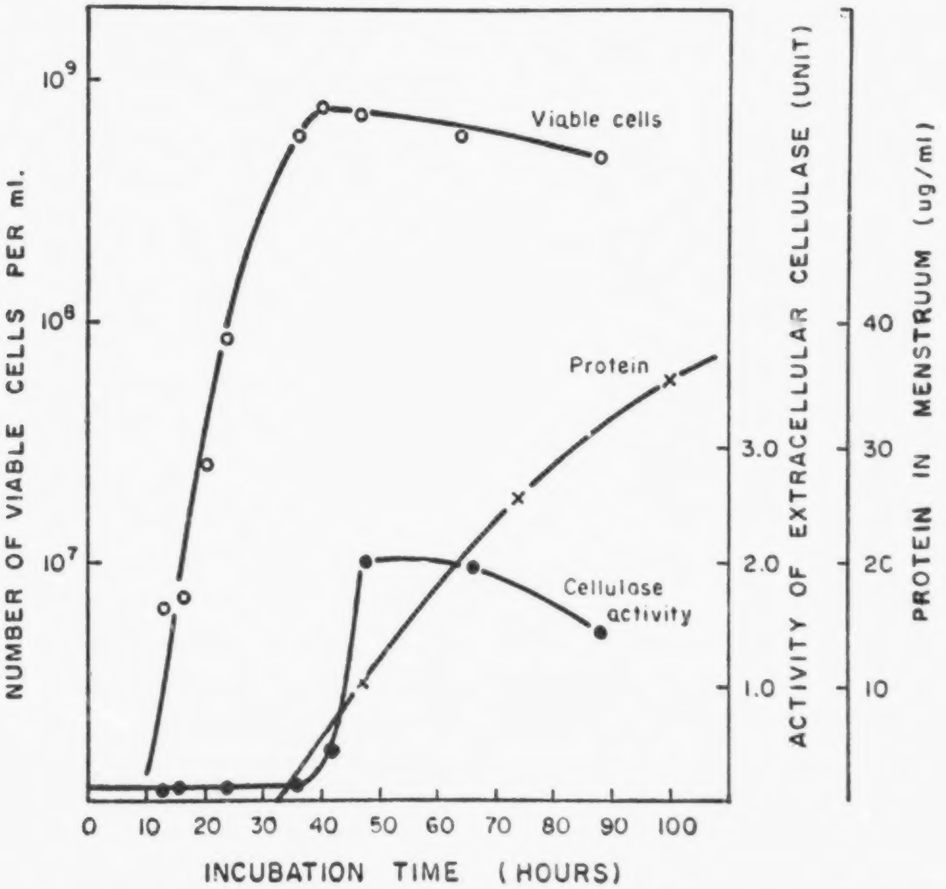

Figure 2: The Growth, Excretion of Protein and the Cellulase Activity in the Menstruum (The Activity of the Enzyme was Expressed in Terms of Solubilized Cellulose)

tween the temperatures 25° and 35°C in the laboratory media. Below 20° and 40° there was a marked decrease in the growth rate of the organism. The optimal growth of the organism was noticed in the pH region of 6-8.

Table 3 presents the digestibility of several cellulosic materials by the organism. It is clear from the table that the isolate is incapable of breaking down native cellulose in the form of cotton fiber. Regenerated cellulose such as filter paper or cellulose powder is digested more easily. Entire bagasse, bagasse fiber, or pith is not broken down efficiently. However, pretreatment of bagasse with alkali results in its becoming a good substrate for the cellulolytic activity of the organism. Hence, efficient conversion of bagasse into single cell proteins entails a preliminary operation of partial delignification and swelling of cellulose fibers of bagasse by alkaline treatment.

TABLE 3
Digestibility of Various Cellulosic
Materials by the Organism

Substrate	*Initial wt. (mg)*	*Residual wt. (mg)*	*Degree of digestion (5)*[a]
Filter paper	90.6	40.7	55.0
Cellulose powder	97.0	64.0	34.0
PAB cellulose	92.9	54.2	41.0
CM cellulose	91.8	66.0	28.0
Azo-cellulose	93.0	74.0	20.5
Cotton fibre	99.4	99.4	0.0
Paper towel	65.4	46.0	30.0
Bagasse pith	73.0	65.4	10.0
Bagasse fibres	90.0	87.0	3.4
Sorgo bagasse	109.2	93.0	15.0
Alkali treated sorgo bagasse	100.0	20.0	80.0

a. Degree of digestion was measured gravimetrically after the organism was inoculated into 100 ml of media containing each substrate as a sole source of carbon. Inoculum was incubated for 5 days at 30 C on reciprocal shaker.

If microbial cells are to be produced in large quantity from bagasse or other cellulosic materials it is necessary to obtain some information about the ratio of the amount of cellulose consumed to the production of cells. Such data obtained from experiments utilizing limiting amounts of CM-cellulose under optimal conditions of temperature and pH are presented in Table 4. Fifty percent of the carbohydrate disappeared and can be accounted for by the yield of microbial cells. This is comparable to the cell yield of cultures of *Candida* grown on glucose. Although the cell yields of *Cellulomonas* seem to be encouraging, economic utilization of this process of production of single cell proteins with *Cellulomonas* with cellulose substrates requires a study of the rate of conversion of properly pre-treated bagasse into cell protein.

TABLE 4
Growth Yields of the Organism
Grown on CM-cellulose

	Yields	
	(mg/mg) in 100 ml	*(%)*
Cell mass[a]/CH_2O consumed[b]	13.0/26.0	50.0
Protein[c]/Cell mass	6.0/13.0	46.2
Non protein-N[d]/Cell mass	1.0/13.0	7.7
Protein /CH_2O consumed	6.0/26.0	23.0

a. Cell crops are dried overnight at 110 C.
b. Difference of CH_2O concentration in initial and final medium.
c. By micro Kjeldahl method after extracting nucleic acid with 5% TCA at 90 C for 30 min.
d. Difference of N content in whole cells and hot TCA treated cell.

Under the experimental conditions of growth it has been found that *Cellulomonas* comprises 23 percent of its dry weight as protein. As an essential step in the evaluation of the nutritional aspects of the product, the quality of the protein is determined by the analysis of the different amino acids present in the product. Table 5 presents the results obtained and the amino acid content of the *Cellulomonas* cell protein as compared with those of other proteins obtained by fermentation of petrochemicals, as well as the essential amino acid pattern of an ideal high quality protein proposed by the Food and Nutrition Board of the Food and Agricultural Organization of the United Nations. It can be seen that the cell protein contains lysine in more than sufficient quantity recommended by FAO. It does not have as much methionine as beef but the level of the amino acid is comparable to that in wheat flour or single cell proteins produced from hydrocarbons.

It has been stressed so far on the feasibility of production of *Cellulomonas* as a large scale source of single cell proteins. In the early experi-

TABLE 5
Essential Amino Acid Content of the Cell Protein[a]
(grams of amino acid per 100 g protein)

Amino Acid	*Cell Protein*	*FAO[b] Reference Protein*	*Wheat[c] Flour*	*Beef[c]*
Arginine	9.21		4.2	7.7
Histidine	2.30		2.2	3.3
Isoleucine	4.74	4.2	4.2	6.0
Leucine	11.20	4.8	7.0	8.0
Lysine	6.84	4.2	1.9	10.0
Methionine	1.86	2.2	1.5	3.2
Phenylalanine	4.36	2.8	5.5	5.0
Tyrosine	2.67	2.8		
Threonine	5.37	2.8	2.7	5.0
Valine	10.71	4.2	4.1	5.5

a. The sample was hydrolyzed with 6 N HCL at 100 C for 22 hours and determined with a Beckman model 116 amino acid analyzer.
b. National Academy of Science — National Research Council.
c. Iyengar, M. S. 1967. Protein from petroleum. Paper presented at single cell protein conference at MIT, Cambridge, Massachusetts.

ments it was found that a small amount of yeast extract was absolutely necessary to ensure a good growth of the organism. Subsequent investigations carried out to find out the growth factor contributed by yeast extract showed that thiamine at a level of 10 μg/ml enable the organisms to grow in the presence of cellulosic substrates, although the rate of growth was slower than that in the presence of yeast extract. If the method of production of microbial protein was to be competitive in cost with other proteins, it is imperative that a reasonable rate of degradation of cellulose has to be obtained. To this effect, studies were undertaken to ascertain the rate of increase of cell mass by mixed inoculation of *Cellulomonas* with another organism.[7] It has been shown that the bacterial cellulase from *Cellulomonas* breaks down the cellulose to cellobiose. Hence, initially a number of organisms were surveyed for their ability to grow on cellobiose as the carbon source. One such organism, preliminarily characterized as belonging to the genus *Alcaligenes* was used to study its interaction with *Cellulomonas* in the breakdown of cellulose. Figure 3 depicts the kinetics of growth of *Cellulomonas* as well as the mixed culture. Growth was monitored by measurement of turbidity in the culture medium containing CM-cellulose as the soluble substrate. The medium contained the basal salt solution supplemented with thiamine. The organism *Alcaligenes*, sp. did not show any visible growth in this medium; whereas *Cellulomonas* was found to grow rather slowly, but at a steady rate. However, a mixed inoculation of both the organisms in the medium resulted in a marked increase in the growth rate of the organisms in the medium resulted in a marked increase in the growth rate of the organisms. A differential count of the two organisms was made during the growth (Figure 4) which showed that the majority of the population in the mixed culture consisted of *Cellulomonas*. Several explanations can be advanced to account for the behavior of the two organisms in the mixed culture. *Cellulomonas* perhaps is able to assimilate cellobiose only at a slow rate, and the accumulation of cellobiose in the medium inhibits the activity of the cellulase, and this results in the retardation of growth. Continuous partial removal of cellobiose by the second organism leads to a removal of the limiting factor of the growth of *Cellulomonas*, namely the cellulolytic activity of the organisms and thereby enhances its growth. Or, it might be that the *Alcaligenes* supplies the necessary growth factor(s) required by the cellulolytic organism. It is also possible that the second organism glucosidase cross-feeds the *Cellu-*

lomonas with glucose from the breakdown of cellobiose. Further experimentation is required before any conclusion can be drawn about the mechanics of interaction between the two organisms.

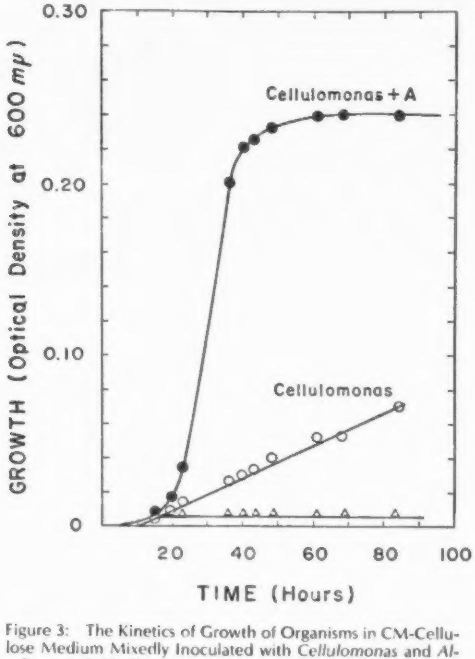

Figure 3: The Kinetics of Growth of Organisms in CM-Cellulose Medium Mixedly Inoculated with *Cellulomonas* and *Alcaligenes* (A-Alcaligenes)

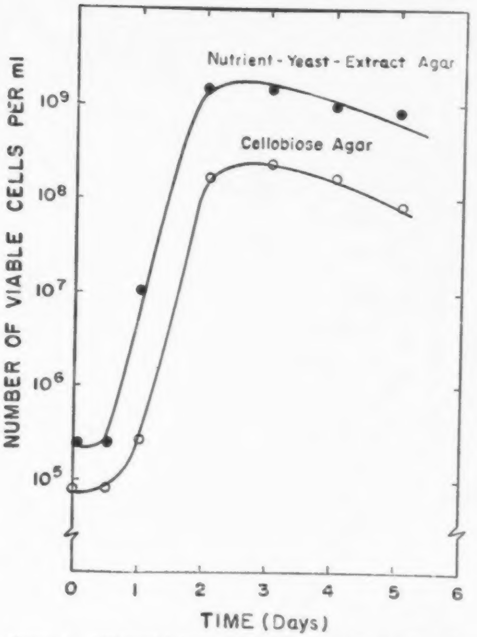

Figure 4: Differential Count of the Organisms During Growth in CM-Cellulose Medium Mixedlv Inoculated with *Cellulomonas* and *Alcaligenes*. (The Counts .---. Give the Total Number of Both the Organisms) o----o Represents the Number of *Alcaligenes* in the Mixture

REFERENCES

1. Brock, Thomas D. Principles of Microbial Ecology, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1966, p. 29.

2. Brungay III, Henry R. and M. L. Bungay. Microbial Interactions in Continuous Cultures, Advances in Applied Microbiology, 10:269-290.

3. Hagen, C. A., E. J. Hawrylewicz, B. T. Anderson, V. K. Tolkacz and M. L. Ewing. Ability of microorganisms to establish ecological niches in different soils and environments. Devel. Indust. Microbiology. 9:401-414, 1968.

4. Han, Y. W. and V. R. Srinivasan. Isolation and characterization of a cellulose utilizing bacterium. Applied Microbiology. 16:1140-1145, 1968.

5. Hawkes, H. A. Ecology of waste water treatment. Macmillan Company, New York, 1963, p. 99.

6. Johnson, Marvin J. Growth of microbial cells on hydrocarbons. Science 155:1515-1519.

7. Srinivasan, V. R. and Y. W. Han. Utilization of bagasse. Advanced Chemistry Series 95:447-460.

Chemical-Bioconversion Pilot Plant for Cellulosic Wastes

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INTRODUCTION

During the past year we have been engaged in the design, construction, and operation of a pilot unit to produce bacterial single-cell-protein by fermentation of cellulosic waste materials. Cellulosic agricultural wastes such as sugar cane bagasse, grain straws, and wasted vines are a most attractive raw material. The yearly annual world of production of bagasse, rice, wheat, coarse grain straws, and soybean vines alone is about 1.7 billion tons. Part of this staggering amount is burned for fuel; most of the rest goes back into the soil.

Cellulose fermentation has received considerable interest for a long while.[1,2,3] The chief drawbacks have been high costs of pre-fermentative treatment, as with the German World War II yeast processes, or low kinetic rates of organism growth and cellulose degradation.

Recently the isolation of several mesophilic and thermophilic bacteria with faster growth rates, and fungi with highly active cellulases, has increased the prospects of profitable cellulose fermentation.[4,5,6]

The LSU pilot unit has been run on sugar cane bagasse and purified ground wood pulp. Bacteria of the *Cellumonas* genus have been produced in both batch and continuous runs.

Cellulose Treatment and Fermentation Process

The pre-fermentative treatment process used in the pilot unit has been a size reduction of the particular cellulosic to be used followed by a mild alkaline-oxidation. The cellulose is contacted with alkali of low concentration and passed through an infrared oven where the alkali catalyzes the degradation reaction with molecular oxygen. The treated cellulose, as it emerges from the oven, has a lower degree of polymerization, and a lower crystallinity than the native material and the lignin occlusion, or binding of the fibrils, is disrupted. The cellulose has increased reactivity and is made from 85 percent to 95 percent more susceptible to enzymatic degradation.

This cellulose is re-slurried with water and inorganic nutrients, sterilized, and fed to the fermentation vessel (Figure 1). If a batch process is being used, the complete media is sterilized in the fermenter.

The fermenter is inoculated with the bacteria; the agitation rate, pH, pressure, tem-

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This work is being performed under the joint sponsorship of the Commonwealth of Pennsylvania Science and Engineering Foundation, and the Federal Water Pollution Control Federation, Department of the Interior, Grant No. 16070EOI

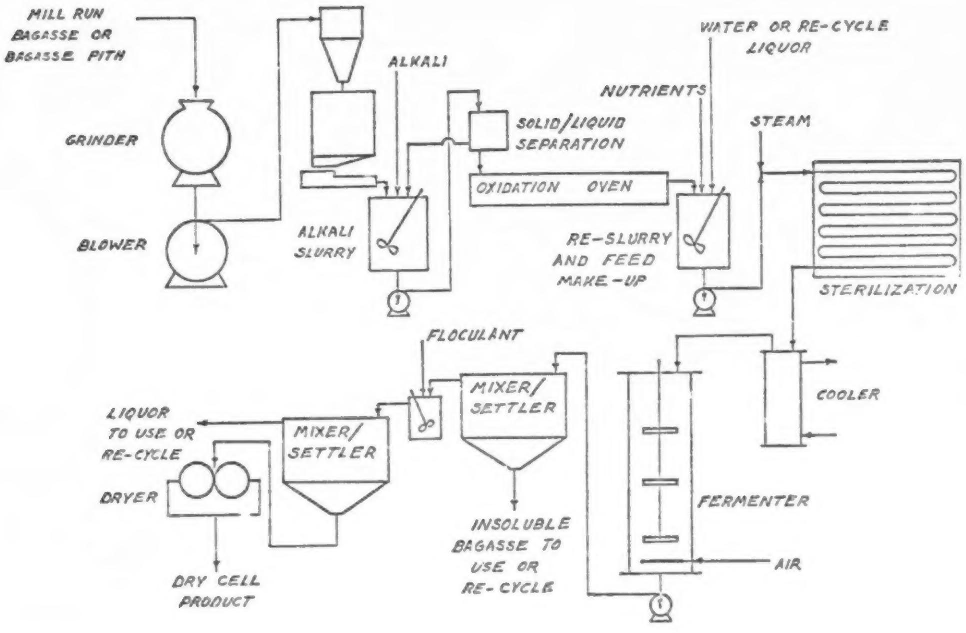
MILL RUN
BAGASSE OR
BAGASSE PITH
GRINDER
BLOWER
ALKALI
ALKALI
SLURRY
SOLID/LIQUID
SEPARATION
OXIDATION OVEN
NUTRIENTS
WATER OR RE-CYCLE
LIQUOR
STEAM
RE-SLURRY
AND FEED
MAKE-UP
STERILIZATION
FLOCULANT
MIXER/
SETTLER
MIXER/
SETTLER
COOLER
LIQUOR
TO USE OR
RE-CYCLE
DRYER
DRY CELL
PRODUCT
INSOLUBLE
BAGASSE TO
USE OR
RE-CYCLE
FERMENTER
AIR

Figure 1: Cellulose Fermentation Unit — Flow Sheet

perature, and rate of aeration are adjusted to the proper settings.

During the run, the concentration of cells is monitored by standard optical density measurements with a Klett-Summerson colorimeter; the sample having been cleared of undigested cellulose by filtration. The concentration of soluble carbohydrate is also monitored by the colorimetric phenol-sulfuric acid technique. The pH and temperature of the media are automatically recorded and controlled; the pressure, aeration rate, and agitation rate are automatically maintained.

For harvesting the bacteria, the culture is pumped over a fine dewatering screen for removal of the major portion of the cellulose remaining undigested. The cellulose that passes through the screen is allowed to settle from the culture in a clarifier unit. That cellulose is withdrawn, and the cells are either removed by direct centrifugation of the culture (if active cellulase enzyme is desired), or are precipitated by a pH adjustment, collected, and dried.

Continuous Feed Stream Sterilization

Han and others[6] at the LSU/MTF facility have found greatly increased kill rates of bacterial spores and vegetative cells when using heat sterilization by sterilizing in an alkaline solution. The pilot plant continuous sterilization system makes use of this phenomenon. When the alkali treated cellulose is re-slurried to make up the feed stream, it brings the alkali content of that stream up to between 0.1 percent and 0.3 percent. The main feed pump then meters the feed into a steam injection heater where the temperature of the stream is raised to 300°F. The stream then goes to an insulated holding section where the feed remains at or near the desired sterilizing temperature for a predetermined length of time. The presence of alkali in the stream (when above 0.175 percent) greatly decreases the D value for organism death, where D equals the time necessary for 90 percent kill. The pH of the feed is then adjusted in the fermenter by acid addition to the media.

Inorganic Nutrients

The initial inorganic nutrients used in the process, $(NH_4)_2SO_4$, NaCl, KH_2PO_4, K_2HPO_4, $MgSO_4$, and $CaCl_2$ plus trace minerals, were all of reagent or laboratory grade. In an effort to decrease processing costs, fertilizer grade chemicals were tried. Ammonium polyphosphate (N = 15 percent, P = 27.1 percent, K = 0 percent) from TVA and field grade ammonium chloride were used successfully as the nitrogen and phosphorous sources.

The media for *Cellulomonas* growth in the pilot unit has a nitrogen-phosphorous-potassium ratio of about 25 - 5 - 1. The laboratory media is about 15 - 5 - 1. This change was made in an effort to increase protein synthesis while minimizing nucleic acid production. Continuing work is being done in attempting to improve the nutrient media to obtain maximum bacterial growth.

Fermentation Experiments

The discussion of experimental data obtained from the pilot plant unit will be confined to data accumulated from batch runs. The plant has been, and is being, run on a continuous flow basis; but those results have not been analyzed sufficiently to include here.

The substrates that have been used include sugar cane bagasse that has been ground to 1/8-inch nominal size, slurried in 2 - 4 percent sodium hydroxide, dewatered, and partially oxidized with heat and molecular oxygen. The second substrate is bagasse treated as above, and washed with water to remove most of the soluble fractions. These include lignin, hemicelluloses, and part of the degraded cellulose. The third substrate was purified, ground wood pulp. Both bagasse substrates contained about 40 percent crude fiber. The unwashed sample had, of course, a higher over-all carbohydrate concentration.

All three substrates supported *Cellulomonas* growth. Log phase mass doubling times for both washed and unwashed treated bagasse were in the range of 1.8 to 3.7 hours. The growth on wood pulp was somewhat slower, with doubling times of about 5 hours.

The initial concentration of soluble carbohydrates in media with unwashed treated bagasse as substrate varied from 500 to 800 mg/liter depending on the substrate loading. The concentration of soluble carbohydrate fell during this logarithmic growth phase of the organism. This may be seen in Figure 2.

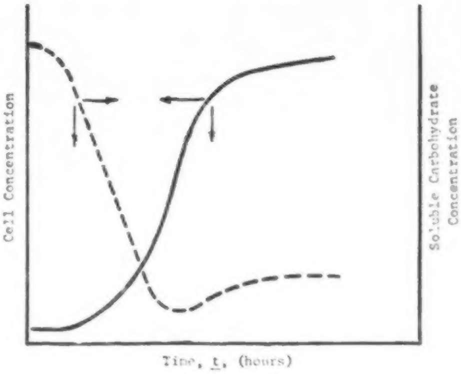

Figure 2: Fermentation of Unwashed Treated Bagasse

Both the soluble carbohydrate decrease and the cell mass increase may be determined from Figure 2. When both these values are calculated over a discrete time period, as long as it is in the logarithmic phase of cell growth, it is seen that the yield coefficient—grams of cell mass increase per gram of soluble carbohydrate decrease—is 0.5, or 50 percent. This is the accepted value for aerobic cell growth on a carbohydrate substrate. This is interpreted to mean that if metabolizable soluble carbohydrate is present in the media in sizable amounts, it will be metabolized almost exclusively to the insoluble cellulose. This has, of course, been well recognized previously, and has been attributed to cellulase enzyme repression or inhibition by the soluble carbohydrate, particularly cellobiose.

When the soluble carbohydrate reaches a low level in these batches, the growth rate slows considerably.

In batches where washed, treated bagasse is used, the initial concentration of soluble carbohydrate ranges from less than 100 to 200 mg/liter. The cells grow and exhibit almost the same kinetics as when grown with higher soluble carbohydrate concentrations, and the concentration of soluble carbohydrate does decrease somewhat. However, the soluble carbohydrate no longer supplies a sufficient quantity of substrate to explain cell mass increase. Therefore, the insoluble cellulose is being degraded and metabolized to some extent whenever initial soluble carbohydrates are low, and the transfer of insoluble cellulose to soluble carbohydrate by enzyme action is appreciable.

In batches with pure wood pulp as the substrate, the initial concentration of soluble carbohydrate is usually less than 50 mg/liter. During the run, the concentration increases until the end of the log growth phase and then decreases. This is shown in Figure 3. It never gets above about 150 mg/liter. In these cultures all of the soluble substrate is being produced by enzymatic breakdown of cellulose.

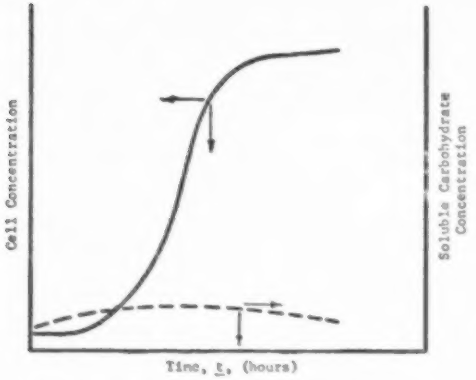

Figure 3: Fermentation of Washed Treated Bagasse

Han[9] has found that the severity of the alkaline-oxidation treatment of bagasse directly affects the amount of carbohydrate that is solubilized, but—after a certain point—does not seem to increase the rate or level of organisms growth. These data indicate that the usefulness of the oxidation is minimal, and—if an active cellulase enzyme system is desired—is distinctly harmful. In other words, it may be best to minimize oxidative breakdown of cellulose. However, a certain mild treatment is necessary since untreated bagasse is metabolized at an extremely slow rate.

If the data from the batch runs by the method of Adams and Hungate[10] are analyzed, constants may be evaluated for use in continuous flow process.

To evaluate the cell production potential for a particular culture in a continuous flow fermenter, X, the cell concentration is plotted versus t, the time (Figure 4). Then the slope of the growth curve, dX/dt is taken at several points and plotted versus X (Figure 5). To find k, the growth rate constant, the slope of a line from the origin to any point on the curve of Figure 5 is taken. In a single stage, backmix fermenter k equals D (the dilution rate, hrs^{-1}), if the cell growth is substrate limited. The predicted equilibrium cell concentration may be taken from the dX/dt curve by dropping perpendicularly to the ordinate X, and reading the concentration. A curve may then be plotted of cell production P—feed rate times equilibrium cell concentration—versus the feed rate to find the optimum operating range of the continuous fermenter (Figure 6).

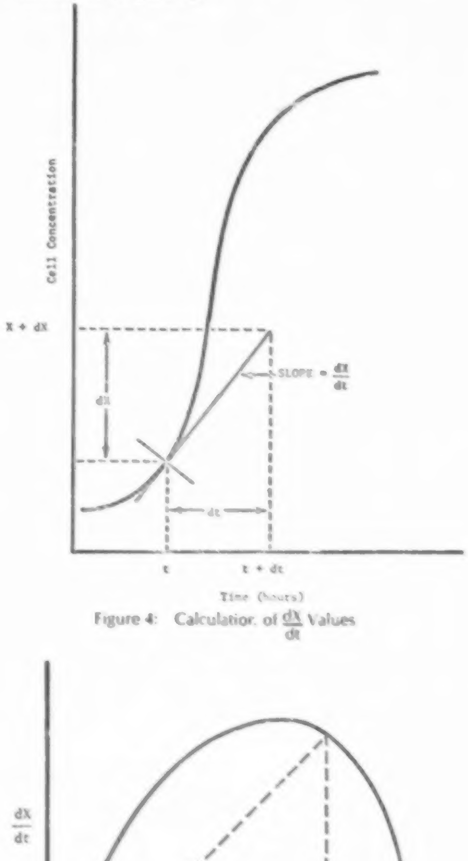

Figure 4: Calculation of $\frac{dX}{dt}$ Values

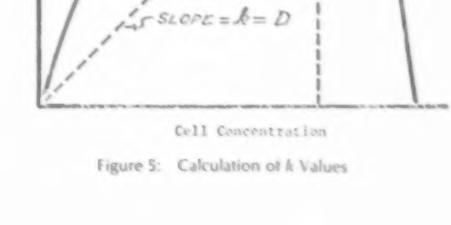

Figure 5: Calculation of k Values

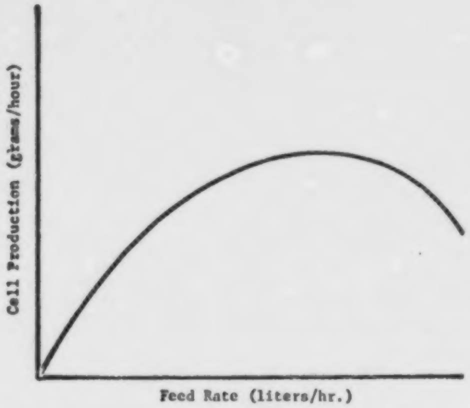

Figure 6: Determination of Maximum Cell Production and Optimum Feed Rate

The maximum volumetric production efficiency (VPE) of the fermenter may be calculated as grams dry cells per liter per hour.

Our batch run data yield VPE values of from 0.05 with wood pulp to 0.072 for treated bagasse. During actual continuous runs, VPE values in excess of 0.10 have been obtained.

The problem of cell density has not been solved. The usual density is about 0.8 to 1.2 gms/liter dry weight after 36 - 48 hour batch runs. Cell density has gone as high as 1.6 gms/liter. It is certainly important to obtain cell densities that are as high as possible, and work is being done to improve this.

Cell Quality and Analysis

Cellulomonas cells grown on purified wood pulp are golden yellow while those grown on bagasse are a deep yellow-brown. It is thought that the lignin harvested with the cells gives them the brown coloring.

Cells harvested by acid precipitation of the cellulose-free media are either centrifuged from the precipitated cream and freeze-dried, or drum dried directly from the precipitate. The centrifuged cells characteristically have 58 - 62 percent crude protein (N × 6.25) and are low in fat, crude fiber, and lignin with about 2 percent of each. Ash content runs from 7 to 9 percent. Much of this is inorganic salts which remained in the precipitated and centrifuged cell cream. Cells harvested by direct drum drying of the precipitated cream are slightly lower in crude protein, fat, and crude fiber; but are much higher in ash. The clear liquid expelled by the centrifuge, therefore, must carry with it most of the inorganic salts. These are retained if the cream is drum dried.

This high-salt, drum-dried product caused an undesirable salt imbalance in rats, which resulted in hydration and greatly increased water passage. Centrifuged, freeze-dried cells did not cause this hydration, but had rather low net protein utilization (NPU) values due to incomplete cell wall rupture. Cell homogenization prior to feeding may raise the NPU values; this is being done at present.

CONCLUSION

While this process is still not thoroughly explored, several conclusions may be reached on the basis of the batch run data.

First, if one desires or is to depend on an active cellulase enzyme system to degrade cellulose, then soluble carbohydrate in the feed must be either minimized or kept to a low level in the fermenter by another symbiotic organism(s). A two-stage fermentation process is also a possible solution.

Secondly, a crude, native cellulose responds to pre-fermentative treatment much better than do processed or pure celluloses.

Thirdly, cell concentration and harvesting must be designed to minimize salt, lignin, and fiber content of the final cells.

Fourth, the alkali-oxidation treatment may be very mild to assure maximum utilization of the cellulose by the bacteria.

LITERATURE CITED

1. Adams, S. L., and R. E. Hungate, *Ind. Engr. Chem.*, 42, 1815, (1950).

2. Bellamy, W. D., *Cellulose as a Source of Single-Cell-Protein — A Preliminary Evaluation*, General Electric Co., report No. 69-C-335.

3. Delbruck, M., *Wschr. Brau*, *27*, 31, 375, (1910).

4. Dunlap, C. E., Ph.D. Thesis, Louisiana State University, (1969).

5. Ghose, T. K., *Biotech. and Bioengr.*, *11*, 239, (1969).

6. Hajny, G. J., C. H. Gardner, and G. J. Ritter, *Ind. and Engr. Chem.*, 43, 6, 1384, (1951).

7. Han, Y. W., H. A. Schuyten, Jr., and C. D. Callihan, unpublished data.

8. Han, Y. W., unpublished data.

9. Srinivasan, V. R., and Y. W. Han, *Applied Microbiology*, 16, 8, 1140, (1968).

10. Virtanin, A. I., J. Hukki, *Suomen Kemistilchti*, 19B, 4, (1946).

An Inventory of Marine Disposal of Solid Wastes

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INTRODUCTION

This paper summarizes the current status of oceanic disposal of barge-delivered liquid and solid wastes from twenty U.S. coastal cities. It is based on a city-by-city field interview program carried out by the Dillingham Corporation Applied Oceanography Division, under Contract PH 86-68-203 with the Bureau of Solid Waste Management, Public Health Service. The principal objective of this program was to determine the nature and magnitude of present oceanic disposal practices from major U.S. coastal cities, thus providing a baseline inventory of available information on sources, characteristics, disposal methods, areas and effects of solid and related wastes discharged in Atlantic, Gulf and Pacific continental shelf waters of the United States.

The principal emphasis of this investigation was on solid wastes and industrial sludges, and the latter were broadly defined so that virtually all liquids being barged to sea (in bulk or in containers) were included. In this broad sense the term solid waste was construed as those materials that will go ". . . neither up the stack, nor down the drain." Many industrial liquids fit this latter category because of their highly corrosive nature: they simply cannot be discharged into a municipal sewage system. Thus, their inclusion in this study.

Prior to this inventory program, there was a general awareness that various solid wastes and industrial sludges (construction debris, dredge spoils, sewage sludge, and industrial acid wastes) were being disposed of at sea but little information on the character and magnitude of such disposal activities was readily available. Our survey shows that substantial amounts of solid wastes and industrial sludges are being barged to sea. Our estimates indicate that some 48 million tons of these wastes were disposed of at sea in 1968 at an estimated cost of $29 million. If dredge spoils are excluded, this estimate is reduced to 9.8 million tons disposed of at a cost of roughly $13.5 million.

The cities considered in this inventory include Seattle, Portland (Oregon), San Francisco, Los Angeles, San Diego, Galveston, Texas City, Houston, Port Arthur, Beaumont, New Orleans, Pascagoula, Mobile, St. Petersburg, Charleston, Norfolk, Baltimore, Philadelphia, New York and Boston. The city-by-city survey included interviews with 179 individuals representing 125 Federal, state and municipal agencies, and organization and industrial firms.

Description of Wastes

Wastes currently being transported aboard barges and ships for disposal at sea from the U.S.

coastal cities surveyed have been summarized into seven major categories and ranked according to total volume. The categories are:

1) Dredge spoil
2) Industrial wastes
3) Sewage sludge
4) Refuse
5) Radioactive wastes
6) Construction and demolition debris
7) Military explosives and chemical wastes
8) Miscellaneous

Although the bulk of these wastes is currently being disposed of on land utilizing various methods such as landfill, ponding, and incineration, substantial volumes have been or are being discharged at sea.

For detailed information regarding the characteristics and problems associated with the disposal of these wastes, the reader should consult the following references: American Petroleum Institute,[1,3] Revelle *et al*,[4] Tarzwell,[5] Moss,[6] U.S. Department of Agriculture,[7] U.S. Coast Guard,[8] Kurak,[9] Sax,[10] California State Department of Public Health,[11] Burd,[12] and Sittig,[13] National Academy of Sciences,[14] and American Chemical Society.[15]

Dredge Spoil

Dredge spoil consist of sediments containing various concentrations of sand, silt and clay dredged to improve and maintain navigation channels. Most of the dredging operations encountered during the course of our survey are conducted by the Corps of Engineers with seagoing hopper dredges. These spoils are normally disposed of in open coastal waters, within areas designated by the Corps. In general, these disposal areas are located offshore and not more than three to four miles from the dredging site.

Industrial Wastes

Industrial wastes originate from a variety of manufacturing and processing operations including petroleum refining, steel and paper production, pigment processing, insecticide-herbicide-fungicide manufacturing, chemical manufacturing, oil well drilling operation, and metal finishing, cleaning, and plating processes, as well as many others. A brief description of several types of industrial wastes currently being disposed of at sea follows.

Refinery Wastes

Wastes from petroleum refining operations are produced during the chemical refining processing used to extract various products from the crude oil. The basic types of refining wastes include spent caustic solutions, sulfuric acid sludges, dilute waste water solutions, spent catalysts, petrochemical wastes and chemical cleaning wastes. In many cases solid wastes, such as spent clay, catalysts and sludges are slurried with liquid chemical wastes for disposal at sea.[2] Aside from the basic chemicals (sulfuric acid, sodium hydroxide, etc.), the spent caustics and acid sludges also contain varying amounts of contaminants including: sulfides, sulfates, phenolates, napthenates, sulfonates, cyanides, heavy metals, mercaptides and other organic and inorganic compounds. Some petro-chemical operations produce by-product chlorinated or brominated hydrocarbons whose physical characteristics can vary greatly depending on the treatment used in the processing.

Spent Acids

Large quantities of spent sulfuric acid containing varying amounts of water-soluble ferrous sulfate are produced by steel mills from the treatment of iron and steel strips, sheets, etc. The acid or "pickle liquor" is usually withdrawn from the operation and disposed of when one-half to two-thirds of the acid is converted to ferrous sulfate. Typical steel mill "pickle liquor" wastes may contain amounts of free acid up to 7 percent and ferrous sulfate up to 30 percent. In recent years some steel mills have converted a portion of their pickling operations to hydrochloric acid which has resulted in a waste stream consisting of a blend of hydrochloric and sulfuric acid and a reduction in the overall volume of wastes.

Another major type of waste acid liquor is produced during the manufacture of titanium pigment. In this process titanium bearing ore, containing iron as a principle impurity, is digested with sulfuric acid. The resulting waste usually consists of between 7 to 9 percent free sulfuric acid and about 8 to 10 percent ferrous sulfate. In addition, a mud slurry containing approximately 15 to 20 percent inert solids in a very weak acid-iron solution is generated with the acid wastes.

Pulp and Paper Mill Wastes

Pulp and paper mill wastes consist of various proportions of organic constituents from wood being pulped, salts used in the digestion process, and fibers which escape processing-all suspended or dissolved in a fresh water media. Depending on the process involved, the wastes produced may contain a sulfate cooking solution (calcium, magnesium or ammonia), "black liquor" (sodium hydroxide, sulfide, sulfate) and organic constituents including lignin, hexose and pentose sugars. In addition to these wastes, "groundwood pulp" consisting of undigested wood pulp is also produced.

Chemical Wastes

Chemical manufacturing, chemical laboratories, metal cleaning, finishing and electroplating processes, and a variety of other industrial operations all produce a host of complex waste chemicals. These include organic acids, pesticides, chlorinated hydrocarbons, alkalies, anilines, cyanides, arsenic-bearing compounds, all of which are highly toxic. Wastes originating from the synthetic chemical industry are noted to be particularly complex in their composition and behavior.

Oil Drilling Wastes

Oil-well drilling wastes currently being disposed of at sea consist primarily of drilling muds containing barite and diatomaceous clays and cuttings (rock chips) from the drill hole. This type of waste can be considered as basically similar to dredging spoils in general physical characteristics.

Waste Oil

These wastes consist principally of oil sludge that remains after any re-refining process. In the case of oil tankers, the wastes are oil residues resulting from tank cleaning operations. Sources of waste oil are numerous and diverse, for example, service stations, ship tanks, tank cars, etc. At the present time the regulations set forth in the Oil Pollution Control Act of 1961 restricts the disposal of these wastes at sea to areas which are beyond the fifty-mile limit.

Sewage Sludge

Municipal sewage consists of aqueous discharges from homes and from a variety of institutional and industrial establishments. Normally, the total solid matter contained in sewage is in the form of large and small particles in suspension or floating, as well as matter in true solution. The weight of these solids usually constitutes 0.03 percent or less of the total sewage solution by weight. Solids are removed and treated by screening, grit removal, primary sedimentation, final sedimentation, anaerobic digestion and thickening. Thickened sludges currently being disposed of at sea from barges range between 3 to 10 percent solids by weight.

Refuse

At the present time only limited disposal of refuse and garbage at sea occurs. These wastes originate primarily from canneries and commercial and naval vessels. Cannery wastes consist of ground fruit pits, skins, etc. and are disposed of on a seasonal basis coinciding with canning operation. The composition of vessel refuse is highly variable depending on the type of vessel, geographic location and season of the year. It consists of varying amounts of garbage, plastics, metal, glass, etc.

Radioactive Wastes

The nuclear energy industry produces various type of waste which are generally categorized as high activity, intermediate activity, low activity and so-called nonactive wastes. High activity wastes have been defined "as those with concentrations of hundreds of thousands of curies per gallon," whereas low activity wastes have concentrations on the order of one microcurie per gallon. The wastes can be solid or liquid and include a wide variety of contaminated materials ranging from laboratory equipment or ordinary gloves to obsolete equipment. Between 1946 and 1967 the United States Atomic Energy Commission disposed of limited quantities of solid packaged radioactive waste materials at designated disposal sites in the Atlantic and Pacific Oceans. In most cases these wastes were packaged in weighted fifty-five gallon drums. Nuclear vessels regularly discharge low-level liquid coolant wastes at sea; this procedure is governed by strict AEC regulations.

Construction and Demolition Debris

These wastes originate from new construction projects and from projects involving the demolition of existing structures, and typically consist of masonry, tile, stone, plastic, wiring, piping, wood and excavation dirt. At the present time, the only sea disposal of this type of waste is from the New York City area.

Military Explosives and Chemical Warfare Agents

This category includes unserviceable or obsolete ammunition such as shells, mines, solid rocket fuels, propellents, pyrotechnics and chemical and biological warfare (CBW) agents. Until 1964, the disposal of explosives was conducted primarily from barges and ships. Since then, gutted World War II Liberty ships have been utilized, being sunk with the wastes aboard in water depths greater than 6,000 feet.

Miscellaneous

Included in this category are various types of rejected or contaminated products, such as foodstuffs, appliances, small batches of toxic wastes (usually barreled) such as pesticides and complex chemical solutions. Wastes in this category are usually disposed of in small lots; records regarding their disposal are difficult to obtain as the disposal operations in most cases are not sanctioned by any regulatory agency.

Location of Disposal Areas

About one hundred and twenty ocean areas designated for the disposal of wastes were identified during the study. The location of these sites for Pacific, Atlantic and Gulf coastal waters, are shown in Figures 1, 2 and 3, respectively. More detailed information on these disposal areas (i.e., water depth, distances from coast) is presented in Appendix C. Figures 1, 2 and 3 also show the location of over one hundred man-made sport fishing reefs constructed from different types of solid wastes, including cars, tires, etc.

The regional distribution of disposal areas for the principal waste categories is summarized in Table 1.

TABLE 1
Number of Marine Waste Disposal
Areas (By Region and Waste Type)

Type of Waste		*Disposal Areas*			
		Pacific	*Atlantic*	*Gulf*	*Total*
Dredge Spoil		10	11	17	38
Industrial Wastes		7	9	6	22
Sewage Sludge			2		2
Refuse		3			3
Radioactive Wastes		6	11	1	18
Explosive Wastes		14	16	10	40
	Total	40	49	34	123

Interestingly, the results show that the number of disposal sites for dredge spoil, industrial wastes and explosives is about equal for all three areas. Most of the disposal sites for radioactive wastes are located off the Atlantic Coast. Disposal sites for refuse are only on the Pacific Coast, and disposal sites for sewage sludge are only on the Atlantic Coast.

Dredge spoil areas are normally located within three miles of the coast in water depths less than one hundred feet.

Most, but not all, of the radioactive and explosive waste disposal areas are situated at depths of 6,000 feet or more. Ocean depths of this magnitude are located 10 or more miles from the Pacific coast and 100 or more miles from the Atlantic and Gulf coasts. The radioactive and explosive disposal areas are identified on U.S. Coast and Geodetic Survey charts and in some cases also serve as disposal areas for toxic industrial waste material.

Industrial and municipal waste disposal areas are situated at distances from 15 to 100 miles offshore depending on the type of waste and established regulatory procedures. For example, acid wastes are disposed of in a designated area 15 miles from the coast of New York City; by contrast, the disposal site for certain toxic chemical wastes is nearly 125 miles offshore. Most industrial waste-disposal operations in the Gulf of Mexico are conducted beyond the 400-fathom line (2,400 feet), which off Galveston requires disposal about 125 miles off the coast.

Selection of Disposal Areas

Results of the present study show that past determinations of whether or not a given offshore area was suitable for waste disposal have been based primarily on the following considerations: 1) the disposal area should be far enough away from the coast and/or have an ocean depth deep enough to ensure that no identifiable wastes return to public beaches or interfere with fishing or recreation in coastal areas, 2) the disposal areas should be within a reasonable distance from the coast so that the costs of tug and barge operations are not excessive. In a small number of cases, the potential harm to the environment, and the restrictions that the waste disposal operations might place on future exploitation of natural resources (i.e., fishing, minerals, oil research) were taken into consideration. Some studies have been conducted of various environmental aspects of individual disposal operations; those, however, have been limited in both scope and duration and in most cases were conducted after the disposal operations were in progress.

Disposal Methods and Costs

Methods employed for sea disposal of the various wastes described in this section consist primarily of transporting the wastes in bulk or containers aboard towed or self-propelled barges. Barging equipment was found to vary from highly sophisticated automated barges to antiquated bulks of Bullwinkle vintage. Bulk wastes are normally discharged from tank barges while underway.

Dredge spoil is handled routinely by U.S. Corps of Engineers aboard their oceangoing hopper dredges. Containerized wastes might, depending on local practices, be weighted and sunk, or ruptured at the sea surface by axes or rifle fire and allowed to sink. In a few cases highly toxic chemical wastes such as arsenic and cyanide are carried to sea regularly as deck cargo on merchant

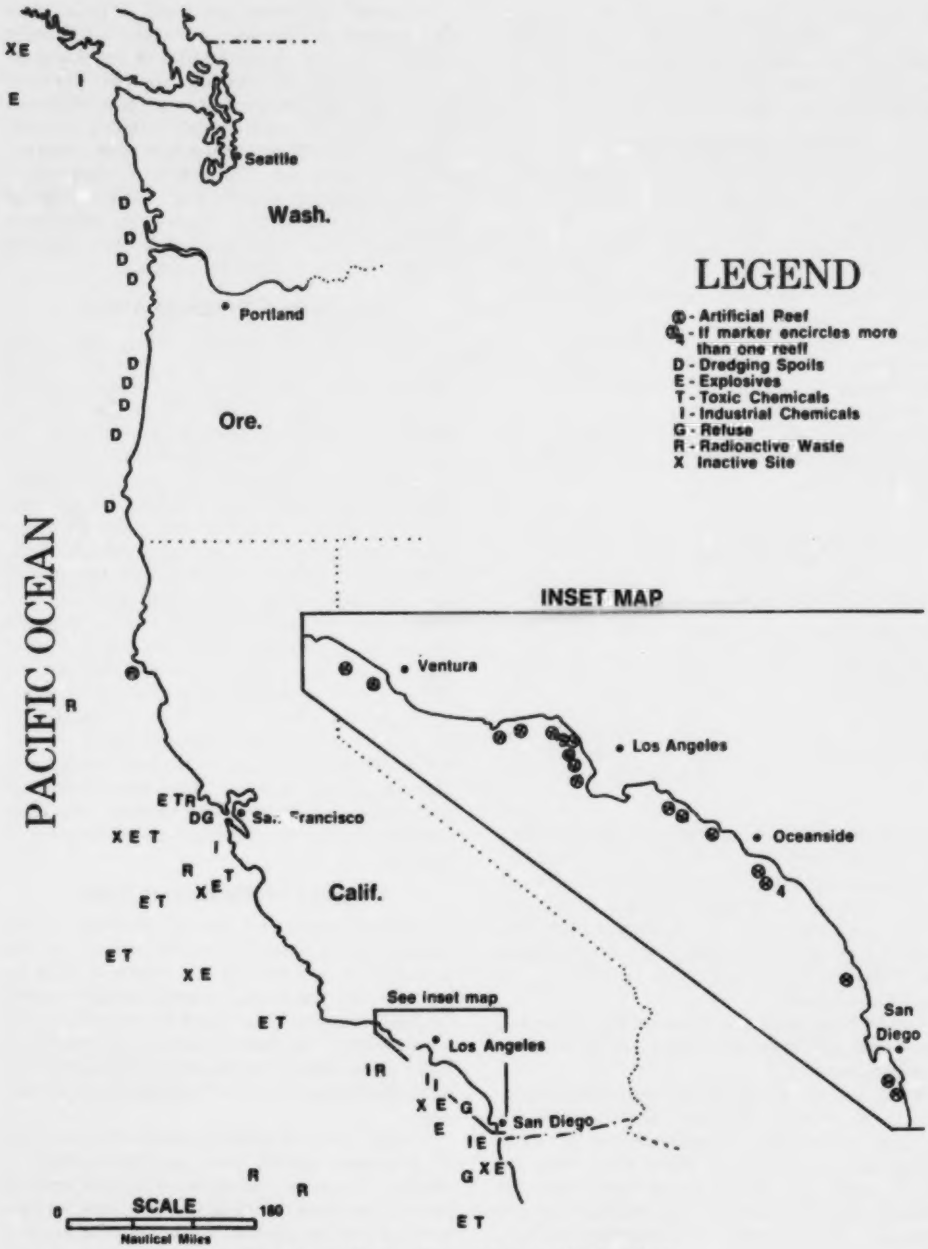
LEGEND
⊗ - Artificial Reef
⊗₄ - If marker encircles more than one reeff
D - Dredging Spoils
E - Explosives
T - Toxic Chemicals
I - Industrial Chemicals
G - Refuse
R - Radioactive Waste
X Inactive Site
PACIFIC OCEAN
Seattle
Wash.
Portland
Ore.
San Francisco
Calif.
See inset map
Los Angeles
San Diego
INSET MAP
Ventura
Los Angeles
Oceanside
San Diego
4
SCALE
0
180
Nautical Miles
XE
E
I
D
D
D
D
D
D
D
D
D
ETR
DG
XET
I
R
XET
ET
ET
XE
ET
IR
I
XE
G
E
IE
GXE
R
R
ET

Figure 1: Pacific Coast Disposal Areas and Artificial Reefs

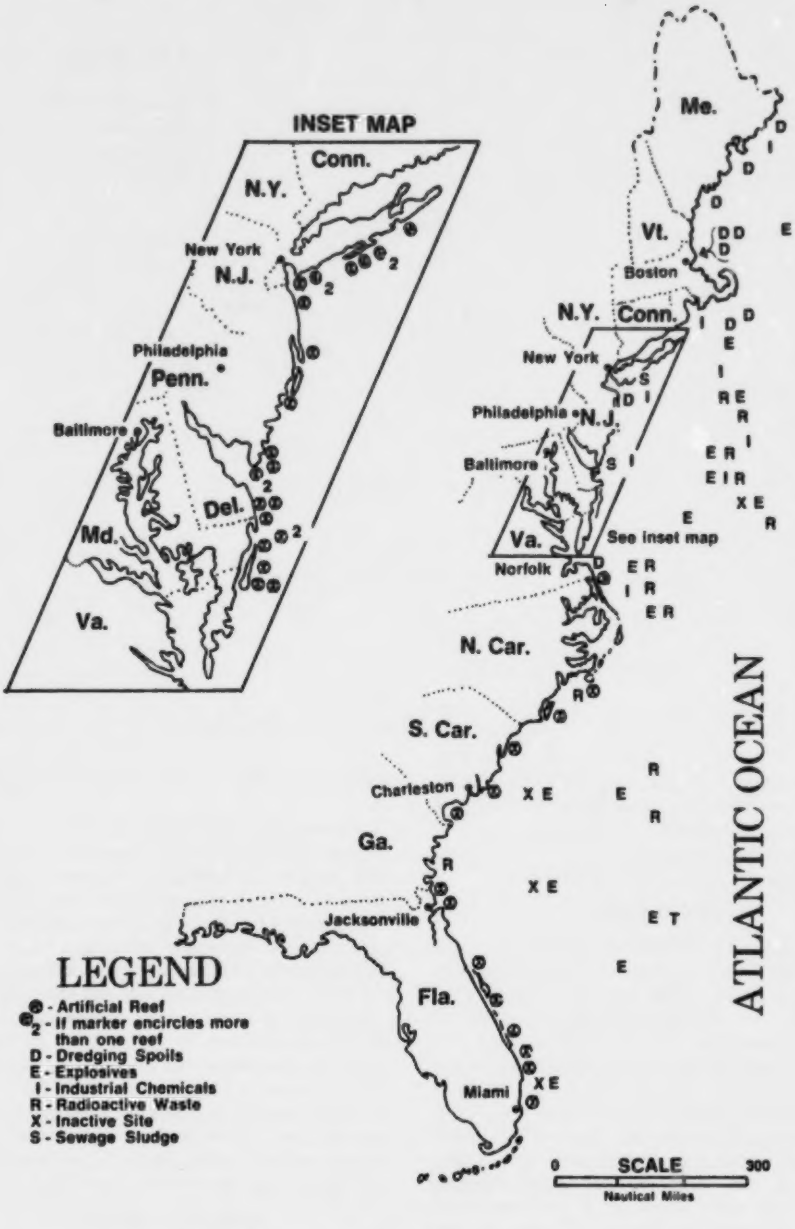
INSET MAP
Conn.
N.Y.
New York
N.J.
Philadelphia
Penn.
Baltimore
Del.
Md.
Va.
2
Me.
Vt.
Boston
N.Y.
Conn.
New York
Philadelphia
N.J.
Baltimore
Va.
See inset map
Norfolk
N. Car.
S. Car.
Charleston
Ga.
Jacksonville
Fla.
Miami
ATLANTIC OCEAN
D
I
E
R
X
S
T
LEGEND
⊗ - Artificial Reef
⊗2 - If marker encircles more than one reef
D - Dredging Spoils
E - Explosives
I - Industrial Chemicals
R - Radioactive Waste
X - Inactive Site
S - Sewage Sludge
0
SCALE
300
Nautical Miles

Figure 2: Atlantic Coast Disposal Areas and Artificial Reefs

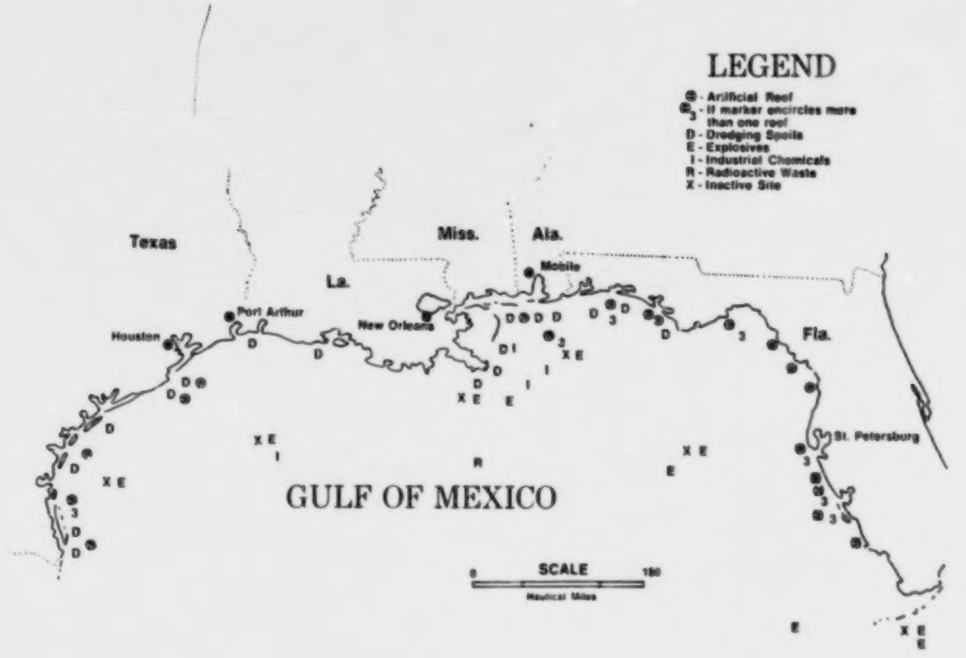
LEGEND
● - Artificial Reef
●3 - If marker encircles more than one reef
D - Dredging Spoils
E - Explosives
I - Industrial Chemicals
R - Radioactive Waste
X - Inactive Site
Texas
La.
Miss.
Ala.
Fla.
Houston
Port Arthur
New Orleans
Mobile
St. Petersburg
GULF OF MEXICO
SCALE
0
100
Nautical Miles

Figure 3: Gulf of Mexico Disposal Areas and Artificial Reefs

ships. The containers are then discharged overboard in undetermined areas once the ship is at least 300 miles from shore. In addition, a number of oil refineries load spent caustics on outgoing crude oil tankers for disposal far at sea.[3]

Dredge Spoil

Ocean-going hopper dredges used by the Corps of Engineers in annual harbor channel maintenance programs resemble a small tanker in general appearance, except for a larger amount of deck equipment. The Corps presently owns and operates a fleet of fifteen hopper dredges in the U.S. coastal and inland waterways. Hopper dredges load by sucking up the bottom sediments through drags, or underwater pipes, while underway in the dredging area. In general, the hauling distance to the spoil disposal areas averages three to four miles, although in the New York area the trip to the designated offshore disposal area is more than 30 miles. An excellent description of hopper dredge disposal techniques is presented by Mauriello and Caccese[16] along with detailed information on the vessels and equipment used.

The average and reported costs per ton for dredge spoil disposal are shown in Table 2. All cost figures for dredging disposal operations given in Table 2 represent the total cost of the dredging operations. The conversion from cubic yards to tons was made utilizing a factor of 1.2 tons per cubic yard for average sediments consisting of a mixture of sand, silt and clay. The average cost of 40 cents per ton differs from the cost of 24 cents per ton computed from information given by Mauriello and Caccese in 1963.[16]. The difference most likely results both from an increase in operational costs over the last five years and the fact that Mauriello and Caccese's observations included all of the 15 hopper dredges operating on both coastal and inland waterways.

Industrial Wastes

Bulk industrial wastes are most commonly transported to sea in tank barges ranging in capacity from 1,000 to 5,000 short tons. These barges must be of double-skinned bottom construction and certified for ocean waters by the U.S. Coast Guard. In addition, U.S. Coast Guard regulations regarding the bulk shipment of chemicals by water[8] must be adhered to. A 5,000 ton capacity barge, *Sparkling Waters*, an industrial waste barge that is currently employed for sea disposal off the New York area was specially built to handle insecticide and other toxic chemical wastes. She is 298 feet by 50 by 20-1/2 feet and cost an estimated $850,000 to construct.[17] This figure includes some $125,000 worth of electrical equipment that enables the tug captain to control the disposal and tank cleaning operations without boarding the barge. *Sparkling Waters* reportedly can be emptied in 30 minutes. Discharge rates of conventional waste disposal barges vary between 4 and 20 tons per minute. The depth at which the wastes are discharged is typically between 6 and 15 feet, and towing speeds from 3 to 6 knots are normally used during the discharge operations. Oceangoing tugs used to haul the barges to the disposal areas are generally of the 1,000-2,000 hp class.

Average and reported range of costs for disposal of bulk industrial wastes are given in Table 2. Because of the wide variation in waste characteristics, tonnages were computed on the basis of the weight of the volume of water in which the wastes were contained. Costs were found to vary considerably depending on the geographical area, type of waste, distance to the disposal area and the annual volume of wastes that were handled by the contract towing firms. Disposal costs estimates for industrial wastes (Table 2) represent a synthesis of the data supplied from three sources: 1) published, 2) waste producers and 3) barging firms. These figures represent actual barging costs and do not include other costs incurred by the waste producers for treatment, storage, loading, etc. of the wastes. Every attempt was made to verify the "ball park estimates" supplied to the study; in some cases, however, discrepancies between the three sources could not be reconciled, and in these cases the costs reported by the waste producer were used.

Toxic industrial liquids and sludges are also disposed of at sea in containers, usually 55-gallon drums. Disposal methods range from regular ongoing operations to odd lots of containers that are discharged on an irregular schedule depending on the local demand. The wastes are transported to sea as deck cargo on either merchant ships or contract disposal vessels. Once at sea, the barrels are jettisoned. Depending on local practices the barrels may be weighted for sinking or ruptured at the sea surface.

The reported costs for disposal of containerized industrial wastes is given in Table 2. The wide range in cost reflects the differences between regular ongoing disposal operations and those where occasional disposal of toxic or hazardous wastes is required by a waste producer. For example, in order to dispose of a single lot of 500 (containing 115 tons of liquid waste) would require the one-time use of a barge and tug. Depending on the geographical area and location of disposal site, this could amount to over two thousand dollars, or $17 per ton.

Refuse and Garbage

Refuse and garbage originating from naval and commercial vessels are transported to sea in various versions of the U.S. Navy's YG class scows. Load capacity varies between 25 and 136 tons.[18] About one trip per week is the average for

TABLE 2
Average and Reported Range of Costs Per Ton for
Marine Disposal of Wastes in U.S. Coastal Waters
1968

	Total U.S.		*Pacific Coast*		*Atlantic Coast*		*Gulf Coast*	
Types of Waste	*Average cost/ton*	*Reported Range $/ton*	*Average cost/ton*	*Reported Range $/ton*	*Average cost/ton*	*Reported Range $/ton*	*Average cost/ton*	*Reported Range $/ton*
Dredging spoils	$0.40/ton	$.20 - .55	$0.43/ton	None	$0.54/ton	$.40 - .55	$0.25/ton	$0.20 - .25
Industrial wastes bulk	$1.70/ton	$0.60-9.50	$1.00/ton	$0.60-9.50	$1.80/ton	$.60-7.00	$2.30/ton	$.75-3.50
Containerized	$24/ton	$5-130	$53/ton	$50-$130	$7.73/ton	$5 - $17	$28/ton	$10 - $40
Refuse and Garbage	$15/ton	$5 - $60	$15/ton	$5 - $60				
Garbage sludge	$1.00/ton	$.80 - 1.20			$1.00/ton	$.80-1.20		
Construction and Demolition debris	$0.75/ton	$.70 - 1.35			$0.75/ton	$.70-1.35		
Explosives	$15/ton	$15 - $90						
Miscel'aneous	$15/ton	$5 - $600	$15/ton	$5 - $600				

these disposal operations. Disposal areas are located at least 20 miles from the coast as prescribed by California Law. Once at sea, flood gates are opened, and the refuse is discharged on the sea surface. Upon completion of the unloading, the tanks are hosed out, and the vessel returns to port. The average total round trip time is six to eight hours depending on sea conditions.

Cannery wastes are disposed of at sea on a weekly basis from the San Francisco area from June to October each year. The wastes are taken to sea aboard a 1,000-ton capacity barge and discharged at the sea-surface as a slurry consisting of seawater and wastes. Discharge operations are conducted at least twenty miles from the coast while the barge is under tow.

The average cost (Table 2) for the disposal of refuse and garbage are about twice the figure usually found quoted for various proposed schemes involving the disposal of municipal wastes at sea.[19] This is because in both the vessel and cannery disposal operations, cost was not the prime consideration. In the case of vessel refuse, California State Law prohibits the disposal of any wastes of foreign origin in city and county landfills without taking adequate precautions to prevent the spread of disease. In the case of the cannery wastes, land disposal in the San Francisco Bay area is difficult because of both the lack of available space and certain health and nuisance problems created by these wastes.

Sewage Sludge

About one half of the total tonnage of sewage sludge disposed of at sea from the New York area is handled by a fleet of five self-propelled barges operated by the city of New York at a reported annual cost of $1.25 million. These barges have capacities between 1200-3200 tons.

In addition to the city-owned sludge barges, contract firms regularly transport sludge to sea from various outlying communities in the New York-New Jersey area. Barging equipment owned by these independent firms is generally in the 3000 to 6300 ton capacity range. The largest of these is *the Ocean Disposal No. 1* which is 226 feet long, 56 feet wise and has a 20 foot draft.[20] The unloading and tank cleaning operations are radio controlled from the towing barge, and the 6300-ton load reportedly can be discharged in 30 minutes.

The round trip distance to the offshore sludge disposal area from the New York City area averages about 25 miles, although it varies depending on the location of a particular treatment plant.

In contrast to the large-scale sludge disposal operations from New York City, sewage sludge from Philadelphia is handled by a single converted tank barge having a capacity of 2700 tons.[21, 23] Total annual cost of this barging is $336,000. About 150 trips a year are made to the disposal area situated about 10 miles off Cape May, New Jersey. The round trip barge-haul to this area is 227 miles and requires about 30 hours of travel time.

Average and reported range of costs for sludge disposal at sea are given in Table 2. The range in costs reflect the variations in hauling distances, annual amount of wastes handled by private contractors and the capacity of individual barges. Burd[12p.320] evaluated the economics of various methods of sludge disposal for the cities of Baltimore, Philadelphia, Washington, D.C., and Camden, New Jersey. He has reported a range of barging costs of between $4 and $25 per dry ton, with the average being $10 per dry ton. Costs of $0.80 to $1.20 presented in Table 2 are for total transported weight, solids and liquids. Burd also reported that, next to pipeline disposal, barging of sludge to sea is the least expensive method now available for the major cities on the eastern seaboard of the U.S.

Construction and Demolition Debris

Construction and demolition debris from the New York City area are disposed both in landfill and at sea. Sea disposal is conducted with 3,000 to 5,000 ton capacity hopper barges that are towed to the offshore disposal area situated some nine miles seaward of the Sandy Hook Light. All construction and demolition wastes handled in this fashion are disposed of in the designated disposal area some 15 to 20 miles off New York City.

As given in Table 2, costs for the disposal of these wastes range from $.70 to $1.35 per ton and average $.75 per ton. Variations in cost reflect differences in the length of barge haul and the amount of wastes handled in a particular contract job.

Military Explosives and Chemical Warfare Agents

Deep-water disposal of outdated munitions and other dangerous military explosives has been the preferred method for many years. Prior to 1964, the wastes were loaded aboard various types of barges and towed to sea for disposal. This method was both expensive and hazardous because of the multiple handling of the material, both onshore in preparing the wastes for disposal and at sea during the actual disposal operations. It has been estimated[9] that it cost $78 per ton to dispose of explosives by this method.

Faced with the high costs and hazards associated with the existing method and the rapid build up of explosive material awaiting disposal, in 1963 the U.S. Navy conceived the idea of the CHASE (Cut Holes and Sink Em) disposal program. The inspiration for this method came from the U.S. Army, which in 1958 scuttled the obsolete World War II vessel, *S.S. Wm. Ralston*, with 8,000 tons of mustard and lewisite gas aboard.[9]

As conceived by the Navy, the CHASE program obtains obsolete, surplus World War II cargo ships which are stripped of any useable equipment or machinery. The ship is then filled with explosive wastes and towed to sea to be sunk by flooding in the designated deepwater disposal sites. To date, twelve such disposal operations have been conducted.

These disposal operations have not been conducted without problems. For example, two disposal ships have unexpectedly exploded upon contact with the sea floor. In addition, as part of the AEC's Vela Uniform seismic test series, the *S.S. Robert L. Stevenson*, loaded with 2,400 tons of explosives, was scuttled in 1967 in 4,000 feet of water off Amchitka, Alaska, with her cargo set for detonation by hydrostatic explosive devices at specified depth. Instead of sinking as planned, she drifted and eventually sank in water shallower than required to trigger the hydrostatic detonators. A subsequent search located the vessel, however, but attempts to detonate her cargo proved fruitless.[23] The Navy terminated the operation on the basis that the detonation attempts indicated that the hulk was no longer a threat. Hydrographic notices and charts now inform interested mariners of the exact location of the *Stevenson*.

Cost figures for the disposal of explosive wastes in Table 2 are for the CHASE operations, involving the *S.S. Mormactern* and *S.S. Richardson*, respectively, which were scuttled in the Atlantic Ocean during 1968. Table 3 presents a detailed cost breakdown for the eleven CHASE disposal operations conducted since 1964.

Radioactive Wastes

The disposal of low-level radioactive wastes has been carried out in the past mainly in weighted containers carried to sea on the decks of barges or ships. The most common method of packaging has been to encase the wastes in concrete contained in 55-gallon steel drums. About three quarters of the volume of these containers is concrete ballast. According to Atomic Energy Commission regulations, the minimum weight of these containers in order to ensure sinking must be 550 pounds.

Pressure tests on the various types of containers have been conducted in the past both in the laboratory and at sea[24,25] to determine if the containers would rupture under increased water pressure as a result of air voids inside the container. The results of these tests have shown that although physical deformation of the containers does occur, the containers maintain their integrity in containing the wastes.

Low-level radioactive wastes resulting from the operation of U.S. Navy nuclear submarines are regularly discharged at sea from the submarines themselves and from storage tanks aboard submarine repair ships. For example, the *U.S.S. Sperry* has three 15,000 gallon tanks for this purpose; the wastes in these tanks must be disposed of at sea in accordance with specific requirements such as depth, rate of pumping, etc.[16]

Costs for the disposal of containerized radioactive wastes at sea have not been included in Table 2 as commercial disposal of these wastes from the U.S. is for all practical purposes nonexistent today. This is primarily because of the greatly reduced costs offered by land burial of solid radioactive wastes which became available in the early 1960's. The unit costs for preparation and handling of radioactive wastes for sea disposal prior to this time have been estimated from several sources to have been on the order of 35 to 50 dollars per 55-gallon barrel. Land disposal is about a third of this cost.

Miscellaneous Wastes

Various types of wastes including barreled chemicals and sludges, defective industrial products, etc. are transported to sea on the decks of barges and ships. In some areas these wastes are "added" to a regular load of wastes whose disposal has been sanctioned by a regulatory agency. As might be expected, no records are kept regarding these operations. The costs of handling disposal of wastes in this manner are strictly based on individual cases. For example, it was noted during one interview that a lot of five barrels of highly toxic chemical sludge had been disposed of at sea along with a regular disposal load at a cost of $50 per barrel, equivalent to approximately $200 per ton net weight.

Tonnage of Current Disposal Operations

As shown in Table 4 during 1968 some 48 million tons of wastes from the civilian and military

TABLE 3
Summary of U.S. Navy CHASE Disposal Operation, 1964-1968[a]

Chase Number	*I*	*II*	*III*	*IV*	*V*	*VI*
Year	*1964*	*1964*	*1965*	*1965*	*1966*	*1968*
Vessel Name	S.S. John F. Shafroth	S.S. Village	M.V. Coastal Mariner	S.S. Santiago Iglesias	S.S. Isaac Van Zandt	S.S. Robert L. Stevenson
Total Cargo	9,799 tons	7,535 tons	4,040 tons	8,715 tons	7,500 tons	6,600 tons
Net Explosive	Unknown	Unknown	512.19 tons	408 tons	1,625 tons	2,327 tons
Disposal Area[b]	Pacific Coast Lat: 37°40'N Long: 123°25'W	Atlantic Coast Lat: 38°49'N Long: 72°14'W	Atlantic Coast Lat: 37°12'N Long: 74°21'W	Atlantic Coast Lat: 37°11'N Long: 74°26'W	Pacific Coast Lat: 39°33'N Long: 125°46'W	Pacific Coast Lat: 51°21'N Long: 171°W
Hull Preparation Cost	$7,949	$3,608	$5,991	$2,235	$50,156	$64,350
Towing Cost[c]	$5,000	$1,000	$990	$1,075	0 (Navy tug)	$39,000
Loading Cost	$102,021	$158,235	$132,979	$178,112	$91,859	$91,000
TOTAL COST	$114,970	$162,843	$139,959	$181,422	$142,015	$155,350
Cost per ton of Total Waste Cargo	$12	$21	$34	$20	$19	$23

Chase Number	*VII*	*VIII*	*IX*	*X*	*XI*	*XII*
Year	*1966*	*1967*	*1967*	-	*1968*	*1968*
Vessel Name	S.S. Horace Greeley	S.S. Corporal Eric G. Gibson	S.S. Monohan	rescheduled for 1969	S.S. Moractems	S.S. Richardson
Total Cargo	6,033 tons	9,004 tons	833 tons	-	7,763 tons	7,437 tons
Net Explosive	442 tons	None	Unknown	-	N.A.	138 tons
Disposal Area[b]	Atlantic Ocean Lat: 36°34'N Long: 74°16'W	Atlantic Ocean Lat: 39°37'N Long: 70°57'W	Atlantic Ocean Lat: 31°40'N Long: 75°56'W	-	Atlantic Ocean Lat: 39°38'N Long: 71°02'W	Atlantic Ocean Lat: 39°33'N Long: 71°02'W
Hull Preparation Cost	$12,566	$32,390	$15,482	-	$31,953	$36,263
Towing Cost[c]	$1,000	$6,850	$15,000	-	$8,131	$6,802
Loading Cost	$90,050	$90,050	$46,000	-	$77,630	$74,435
TOTAL COST	$146,006	$129,290	$76,482	-	$117,714	$117,435
Cost per ton of Total Waste Cargo	$24	$14	$92	-	$15	$16

a. Source: U.S. Navy Ordnance Systems Command, Washington, D.C.
b. Tow Distance was beyond designated Deep Water Disposal Site.
c. Cost includes tow from reserve fleet to shipyard to loading activity, to disposal site.

sector were disposed of at sea at an estimated cost of $29 million. If dredging spoils are excluded, this estimate is reduced to 9.8 million tons disposed of at a cost of roughly $13.7 million. On the basis of total tonnage (excluding spoils) marine disposal from the Atlantic coastal cities is more than eight times as great as that from either the Pacific or Gulf coastal cities.

Dredge Spoil

In volume and cost, dredge spoil is by far the largest of the waste categories being discharged at sea; it constitutes 38 million tons or 80 percent of the total tonnage, and $15.5 million or 53 percent of the cost of all marine waste disposal. In spite of magnitude, dredge spoil ranks low on the scale with respect to producing adverse effects on the marine environment.

Dredge spoil discharged at sea off the Pacific Coast is about one-half that disposed off the Atlantic and Gulf Coasts. The reason for this is the practice in the State of California of returning sand and other sediments dredged from harbor entrances to the land for beach restoration or landfill operations. The location of dredge spoil disposal sites shown in Figures 1, 2 and 3 clearly reflects this regional pattern.

Industrial Wastes

Industrial waste tonnage and costs are the second largest waste category. The 4.7 million tons of bulk industrial wastes (10 percent of the total

TABLE 4
Summary of Type, Amount and Estimated Costs of Wastes Disposed of in Pacific, Atlantic, and Gulf Coast Waters 1968

Types of Waste	Pacific Coast		Atlantic Coast		Gulf Coast		Total		% of Total	
	Annual Tonnage	*Estimated Cost $*	*Annual Tonnage*	*Estimated Cost $*	*Annual Tonnage*	*Estimated Cost $*	*Annual Tonnage*	*Estimated Cost $*	*Tonnage*	*Cost*
Dredging spoils	7,320,000	3,175,000	15,808,000[a]	8,608,000	15,300,000	3,800,000	38,428,000	15,583,000	80%	53%
Industrial waste bulk	981,000	991,000	3,011,000	5,406,000	690,000	1,592,000	4,682,090	7,989,000	10%	27%
Containerized	300	16,000	2,200	17,000	6,000	171,000	8,500	204,000	1%	1%
Refuse and Garbage[b]	26,000	392,000					26,000	392,000	1%	1%
Garbage sludge[c]			4,477,000	4,433,000			4,477,000	4,433,000	9%	15%
Miscellaneous	200	3,000					200	3,000	.%	3%
Construction and Demolition debris			574,000	430,000			574,000	430,000	1%	2%
Explosives			15,200	235,000			15,200	235,000	1%	1%
Solid wastes[d]	8,327,500	4,577,000	23,887,400	19,129,000	15,996,000	5,563,000	48,210,000	29,269,000	100%	100%

a. Includes 200,000 tons of fly ash.
b. At San Diego 4,700 tons vessel garbage at $280,000 per year were discontinued in November, 1968.
c. Tonnage of wet basis.
d. Radioactive wastes omitted.

tonnage) discharged at a cost of nearly $8 million (27 percent of the total cost) by 50 separate industrial waste producers was distributed as follows:

Major Types of Industrial Waste	*Percent of Total Industrial Wastes*	
	Tons	$
Waste Acid	58%	59%
Refinery Wastes	12%	7%
Pesticide Wastes	7%	15%
Paper Mill Wastes	3%	7%
Others	20%	12%

It should be noted that although the total amount of industrial wastes disposed of at sea is not much more than sewage sludge, the costs for disposal of industrial wastes are about twice as great.

As shown in the following table, when coastal cities (disposing of more than 12,000 tons of waste per year at sea) are ranked according to tonnage, New York's disposal operations have tonnages more than four times as great as Los Angeles, and nearly one-third more than the total tonnage of the other eight city complexes considered.

	Tons per year
New York City	2,700,000
Los Angeles	660,000
Houston-Galveston-Beaumont, etc.	320,000
New Orleans	300,000
Philadelphia	290,000
San Francisco	200,000
Seattle	120,000
Norfolk	60,000
Mobile	12,000

It should be noted that waste acid makes up over 90 percent of the total industrial wastes being disposed of at sea from New York City. Similarly, the bulk of the tonnage discharged from Los Angeles consists of sediment-like oil drilling muds and cuttings. To date, both of these have been considered to be relatively harmless in terms of environmental pollution.

Refuse and Garbage

The total volume of refuse and garbage currently being disposed of at sea is small (less than 1 percent of tonnage and cost) compared to most other wastes, and is confined to the Pacific coast. Major sources are from naval and commercial vessels and cannery operations.

Sewage Sludge

Sewage sludge (from the cities of New York and Philadelphia) ranks third as to tonnage and cost: 4.5 million tons (9 percent of total) and $4.4 million (15 percent of cost). The total amount of sludge from the New York area is about ten times as great as that discharged by the city of Philadelphia. It is noteworthy that both these operations are projected to increase considerably over the next five to ten years. In addition, the city of Baltimore intends to begin disposing of some 400,000 tons of sewage sludge per year in 1970 in the disposal area now used by the city of Philadelphia.[27]

Construction and Demolition Debris

The disposal of these wastes at sea occurs only from the city of New York and represents an alternate solution to offset the lack of available landfill. As might be expected, the total amount of wastes discharged on a yearly basis could vary considerably depending on the current status of construction operations.

Military Explosives and Chemical Wastes

The total tonnage of military explosives shown in Table 5 represents the total cargo that was sunk at sea during CHASE operations XI and XII. As shown in Table 3, the disposal of these wastes at sea is intermittent and depends on the backlog of outdated munitions that develop at individual military ordnance depots.

Radioactive Wastes

These wastes have not been included in Table 4 since for all practical purposes the disposal of radioactive wastes at sea from the U.S. was nonexistent in 1968. As a basis for comparison, however, a summary of the sea disposal of U.S. radioactive wastes from its inception in 1946 to its termination in 1967 (prepared from data supplied by the AEC) is given in Table 5.

TABLE 5

Total U.S. Sea Disposal of Radioactive Wastes 1946 through 1967[1]

Disposal Area	*Number of Containers*	*By-product material (curies)*	*Source material (pounds)*
Pacific Ocean	52,538	14,708	
Atlantic Ocean	33,998	79,484	1,885
Gulf of Mexico	1	10	
	86,537	94,202	1,885

[1] Source: U.S. Atomic Energy Commission, Division of Operational Safety.

Miscellaneous Wastes

The data shown in Table 4 for this type of waste are only crude approximations. It is known with certainty that small volumes of wastes such as toxic chemical sludges, rejected industrial products, etc., are being disposed of at sea on a clandestine basis, but no clear picture as to tonnage or cost is available because of the nature of these operations.

REFERENCES

1. American Petroleum Institute, Manual on Disposal of Refinery Wastes, Volume III, Chemical Wastes, Fourth Edition, American Petroleum Institute, Division of Refining, New York, New York, 1960, 93 pp.

2. American Petroleum Institute, Manual on Disposal of Refinery Wastes, Volume VI. Solid Wastes First Edition, American Petroleum Institute, Division of Refining, New York, New York, 1963, 51 pp.

3. American Petroleum Institute, Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes. First Edition, American Petroleum Institute, Division of Refining, New York, New York, 1969.

4. Revelle, R., et al, The Effects of Atomic Radiation on Oceanography. National Academy of Sciences, National Research Council. Publication No. 551, 1957, 137 pp.

5. Tarzwell, C. M. (Editor), Biological Problems in Water Pollution, Transactions, U.S. Public Health Service (Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio), 1960.

6. Moss, J. E., Character and Control of Sea Pollution by Oil, American Petroleum Institute, Division of Transportation, Washington, D.C., 1963, 122 pp.

7. U.S. Department of Agriculture, Proceedings of the Federal Inter-Agency Sedimentation Conference. Miscellaneous Publication, No. 970. Agriculture Research Service, U.S. Department of Agriculture, 1963.

8. U.S. Coast Guard. Chemical Data Guide for Bulk Shipment of Water. Transportation Department (formerly U.S. Treasury Department), Government Printing Office, Washington, D.C. 1966, 132 pp.

9. Kurak, S. Operation CHASE. U.S. Naval Institute Proceedings. Volume 93, Part 2, September, 1967, pp. 40-46.

10. Sax, N. K., Dangerous Properties of Industrial Material. Reinhold Book Corporation, New York, New York, 1968, 1231 pp.

11. California State Department of Public Health. Status of Solid Waste Management in California. California State Department of Public Health. Sacramento, California, 1968.

12. Burd, R. Y., A Study of Sludge Handling and Disposal. Water Pollution Control Research Series, U.S. Department of Interior, Federal Water Pollution Control Administration. Publication WP 20-4, 1968, 326 pp.

13. Sittig, M. Water Pollution Control and Solid Wastes Disposal. Noyes Development Corporation, Park Ridge, New Jersey. London, England, 1969, 244 pp.

14. National Academy of Sciences - National Research Council. Waste Management and Control Committee on Pollution, National Academy of Sciences - National Research Council Publication 1400, Washington, D.C., 1969, 257 pp.

15. American Chemical Society. Cleaning our Environment. The Chemical Basis for Action. American Chemical Society. Washington, D.C., 1969, 249 pp.

16. Mauriello, L. J. and Caccese, L. Hopper Dredge Disposal Techniques and Related Developments in Design and Operation Paper No. 65 In the Proceedings of the Federal Inter-Agency Sedimentation Conference, 1963.

17. Anon. At Sea about Chemical Wastes. Chemical Week, October 14, 1967, McGraw-Hill, New York, pp. 113-4.

18. Marlil and Pomeroy, Engineering Study of Refuse Collection and Disposal at San Diego Area Naval Installation. Report to Southwest Division Bureau of Yards and Docks United States Navy, San Diego, California, Unpublished Report.

19. Metcalf and Eddy/Engineers. New York State Pure Waters Authority. Rail-Haul Disposal of Solid Wastes for Westchester County, New York. Summary Report. 1969.

20. Anon. New Sludge Barge Enters Operation for Ocean Disposal Company in New York area. Maritime Reporter and Engineering News. April 15, 1969, p. 8.

21. Anon. Sludge Disposal at Sea. Civil Engineering - ASCE, August, 1968, p. 62-63.

22. Guarino, C. F. Sludge Disposal in Philadelphia by Barging to Sea. Paper presented at the 38th Annual Conference, Pennsylvania Water Pollution Control Association, Pennsylvania State University. 1966, (Unpublished manuscript).

23. Daugherty, F. M., Jr., and Carrell, J. C. Search for the "Stevenson" Undersea Technology. Compass Publication. Arlington, Virginia. April, 1968, pp. 26-46.

24. Pneumo Dynamics Corporation. Survey of Radioactive Waste Disposal Sites. Technical Report ASD 4634-F, prepared under Contract AT(04-3)-331 for the United States Atomic Energy Commission, 1961, 131 pp.

25. Pearce, K. W. and Vincent, J. D. Investigation into the Effects of Deep Sea Pressures on Waste Materials and Disposal Containers. United Kingdom Atomic Energy Authority, Harwell, AERE-M-1254, 1963.

26. Personal Communication with George D. Ward and Associates. Pollution Control Consultants, Portland, Oregon, June 16, 1969.

27. Stein, J. F. Observations on the Disposal of Sodium Sludge in the Gulf of Mexico. Texas A & M Research Foundation, A & M Project 147, Reference 56-36T. 7 pp. Unpublished manuscript.

Pipeline Transport for Oceanic-Placement of Concentrated Solid Wastes

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A study has been underway to determine the feasibility of collecting and delivering concentrated waterborne wastes from the Philadelphia Region to a point beyond the edge of the continental shelf where deep water and offshore currents exist. The complete analysis of ecological effects is part of a long term study (viz. 3-5 years). Preliminary studies indicated that a pipeline would be the preferred method for delivery of these wastes for both technical and economic reasons. Whereas a specific industrialized region has been selected for the study, the basic findings will apply to many coastal and inland metropolitan regions.

Waste Inputs

It is intended that the waste input to the line would consist of concentrated dissolved or suspended wastes, which are now being buried, burned or dumped directly into the Delaware River, its estuary or the shallow near shore waters of the continental shelf. Consequently, one of the major tasks in the study basic to overall design has been to define the exact types and quantities of wastes in the Region that would be suitable for disposal by such a system. It was determined that only concentrated waterborne wastes could be considered for such a system, since the economics of pipe cost and undersea laying rise sharply with increasing pipe diameter. A pipe diameter of 3 to 4 feet appeared as the maximum size which would be considered. This would permit flows of up to 16 million gallons per day.

Figure 1 shows the overall approach available for the management of waterborne wastes. The concept under investigation in this study is represented in the lower right hand corner. At the first level of managing waterborne wastes, there is the avoidance of waste generation. This could mean in some cases the total elimination of existing practices. The second level of waste management includes recycle and reuse. Prompted by economic incentives as well as mounting legal pressures, wide varieties of methods are developing in these areas.

Where waste avoidance, recycle, or reuse are impractical, waste water treatment is a necessity, particularly where large volumes of dilute wastes are generated as is commonly the case. Treatment processes, whether they be physical, chemical or biological, result in two outputs. First, there is the large volume of treated water of a

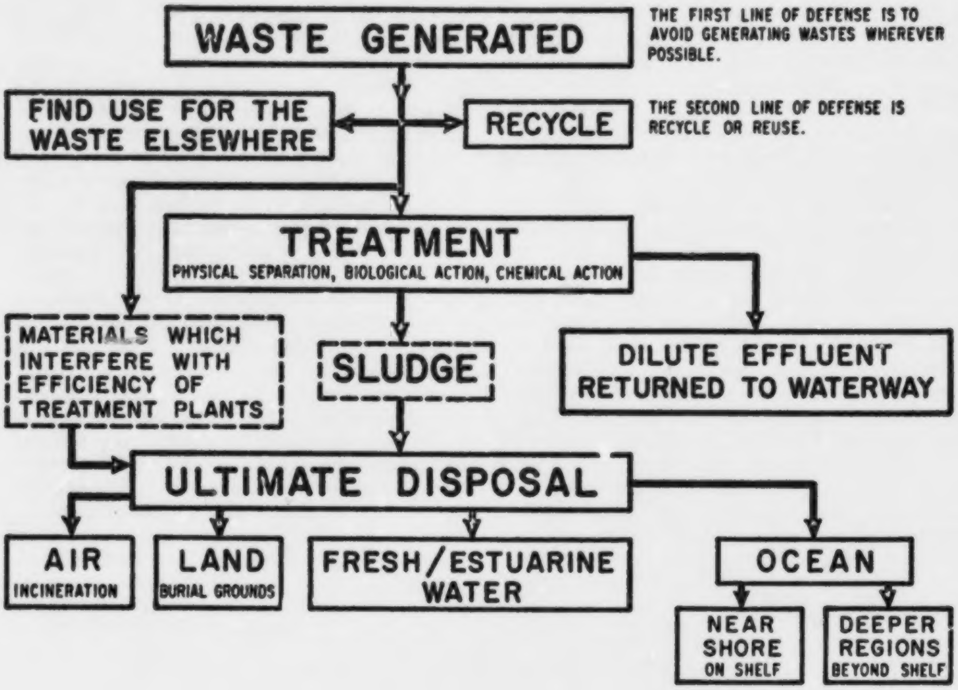
WASTE GENERATED
THE FIRST LINE OF DEFENSE IS TO AVOID GENERATING WASTES WHEREVER POSSIBLE.
FIND USE FOR THE WASTE ELSEWHERE
RECYCLE
THE SECOND LINE OF DEFENSE IS RECYCLE OR REUSE.
TREATMENT
PHYSICAL SEPARATION, BIOLOGICAL ACTION, CHEMICAL ACTION
MATERIALS WHICH INTERFERE WITH EFFICIENCY OF TREATMENT PLANTS
SLUDGE
DILUTE EFFLUENT RETURNED TO WATERWAY
ULTIMATE DISPOSAL
AIR
INCINERATION
LAND
BURIAL GROUNDS
FRESH/ESTUARINE WATER
OCEAN
NEAR SHORE
ON SHELF
DEEPER REGIONS
BEYOND SHELF

Figure 1: Approach to the Management of Waterborne Wastes

quality which permits its being returned to natural waterways. Then there are the residuals, generally in the form of sludges. The superabundance and low utility of these residues mean that some form of ultimate disposal in the natural environment must be carried out. In a very small number of instances as, for example, the case of radioactive wastes, the residues must be contained and stored. Returning the materials in these residues to nature, in a well controlled and ecologically non-disruptive manner, has become a growing technical and economic problem. Since the large volumes of sludges are usually generated where heavy industrial and municipal development has already occurred, open land for disposal use is at a premium. Incineration is likewise a costly alternative, particularly on a large scale. Disposal into fresh water rivers or into the estuarine or nearshore waters of the continental shelf has had the edge from the cost point of view. All of these methods of ultimate disposal have been used and with reasonable success up until recent times. However, the increase in their usage as a result of the rapid industrial and population expansion of the past few decades has made it apparent that most of these methods are beginning to overburden the environment, for example, burial grounds have created ground water pollution; incineration, particularly of chemical sludges has created air pollution problems. The seriousness of pollution of fresh water lakes, rivers and estuarine, and coastal waters has also become apparent.

It is primarily for the above reasons that the present study on collecting and delivering waterborne wastes to a region on the upper Continental slope was undertaken. It was soon discovered that in addition to the unusable residues from various treatment processes there were other untreatable residues available, such as dredge spoils, acids, salts, and chemicals. Many of the latter components create upsets if fed into treatment systems or ecological disturbances if dumped excessively into slowly assimilative regions of the environment.

A preliminary summary of the volumes and compositions of wastes found to be available in the Philadelphia Region for the ocean pipeline system is given in Figure 2.

It is seen that of the four major components, dredge spoils could constitute over three-fourths of the volume input to the line. Because of the relative yearly constancy of this component and its overwhelming volume in the total input, it is seen that the design size of the line would be relatively fixed and not subject to future changes. Each year, 1.4 billion gallons (7 million cubic yards) are dredged from the Delaware River with an average solids content of 42 weight percent. Fine clays are 95 percent of the solids (kaolinite and montmorillonite) with a particle size of about 2 microns; the remaining 5 percent solids are sand and coarse gravel — with some 2-inch stones. The latter solids would be removed from the spoils by rapid settling prior to input to the ocean pipeline. This would avoid abrasion and flow problems. The bulk of the spoils, the very slow settling 2 micron solids, would be diluted to one-third of their original concentration to increase the fluidity of the suspension. It should be noted that a two-fold dilution might be more than adequate to ensure spoil pumpability according to recent studies by the Corps of Engineers on long distance pumping of spoils.[1] Available spoil grounds are being rapidly filled along the Delaware River. In addition, the water pollution and ecologic harms resulting from the use of the many vast estuarine spoil grounds (300 acres per minimum spoil ground) are currently under debate. A major fraction of our food and ocean sport fish are spawned or spend their early years in estuarine waters. High microbial growth occurs in the turbid waters of spoil grounds, and their run off disrupting normal estuarine ecology. Consequently, it appears that dredge spoils can be considered a significant water pollution potential in estuarine waters. In addition, recent studies in the shallow dump water 10 miles off New York Harbor (Figure 3) indicate that their disposal in near shore tidal shelf waters is also ecologically disruptive.[2]

The next major component found for input to the wasteline is sewage sludge at about 10 weight percent solids. These include the hydroxide

Total Flow Volume: 16 mgd (5,840 mgy)

COMPONENT	VOLUME, mgd	% of TOTAL VOLUME	SOLIDS CONTENT, %
1. DREDGE SPOILS Fine Clays + Trace Organics	12.5	78	14
2. SEWAGE SLUDGES Organic: Cellulose-Proteins-Fats Inorganic: SiO_2, Fe_2O_3, NH_4NO_3, $PO_4^{\equiv}$, K^+	1.6	10	3
3. WASTE ACIDS, SALTS, AND CHEMICALS HCl. H_2SO_4, $FeSO_4$, $FeCl_3$ Mixed Organic Acids, salts, and chemicals Filter Aids and chemical sludges	1.6	10	3
4. ASHES Fly Ash, Incinerator Top Ash, Assorted Bottom Ashes	0.3	2	3
	16	100	(10.8) avg.

Figure 2. Preliminary Summary of Volumes and Composition of Waterborne Wastes for an Ocean-Pipeline

sludges from water treatment plants, as well as the primary and secondary sludges from wastewater treatment plants.

The 100 million gallons per year of sludges from the Philadelphia Treatment Plants now constitute about 70 percent of the total available sludge volume for the wasteline. The City of Wilmington, Delaware, follows Philadelphia way down in second place, currently generating about 1/10 of Philadelphia's sludge volume. With the likelihood of the two forthcoming combined Regional Treatment Plants (municipal-industrial plants) at Deepwater, New Jersey, and Marcus Hook, Pennsylvania, the sludge volume for the Region will become approximately 182 million gallons per year.

Waste acids, largely from pigment plants in the Region and waste salt and chemical mixtures including spent catalysts and other chemical sludges, such as, filter aids constitute a volume approximately equivalent to the sewage sludges of the Region. Some relatively dilute chemical wastes which would be inappropriate for treatment or for disposal in the river or in private lagoons would also be included here. The latter would be a small part of the input.

The fourth and smallest component found for the wasteline is ash; fly ash, incinerator top ash, and assorted fine bottom ashes. A small portion of the fly ash from coal burning power stations is being used in the construction industry, however; the major portion is disposed of. Conversion from coal to low sulfur oil is underway in the Region in order to reduce SO_2 generation. However, the small fraction of ash in the waste inventory makes the overall design insensitive to whatever changes occur in this situation.

It should be noted that no significant large quantities of oils or other flotable organics were found in the Region, since waste heat burners are in use at the six refineries in the Region. In addition, tarry and acidic oils are routinely drummed and tossed from ocean going tankers. Dilute oils in waste water effluent are readily biodigested, in cases where these effluents are sent to treatment plants and consequently do not carry over into the sludges.

Overall Description of the System

As the study matured it could be seen that relatively few or possibly just one pick-up station would be required in order to take care of the entire waste load. The wastes would come from within 25 miles of central Philadelphia. Since the bulk of the dredge spoils are removed from the channel between Philadelphia and Marcus Hook, Pennsylvania, and since this would potentially be the main component of the line, an input station on the New Jersey side south of Camden would be advisable. Other wastes and sludges could be stored and shipped to this station by barge, rail or truck tank cars or possibly even pipeline. Discussions with Mr. L. Caccese, Chief Operations Division Philadelphia District, U.S. Corps of Engineers, indicated that an existing spoil ground in this area might be modified and used to impound other waste materials prior to their controlled addition with dredge spoils to the wasteline.

Figure 3 shows the most probable route for such a potential wasteline. Starting near Camden, New Jersey, the line would follow one of several existing rights of way to a point near Atlantic City, New Jersey. Rail lines, electric lines, and the Atlantic City Expressway exist between these points.

Three pumping stations at 20 mile intervals would keep the pump pressures required below 100 psig using 4 foot pipe. A fourth pumping station at the shore would be required to generate a head of approximately 250 psig for the 80 mile undersea leg to the 1,200 foot outfall site on the slope. A 2 feet/second (1.3 miles/hour) flow velocity would be used to minimize friction loss yet keep particles in suspension. This would give the wastes a 4 to 5 day residence time in the line. The 2 day residence time in the overland portion of the line would permit adequate monitoring of waste behavior in the system and permit any necessary additions or corrections to be made (such as ozonation or chlorination) at the last pumping station before dismissal to the sea. An easily monitored and well administered system such as a single pipeline would avert accidental disruptions of the ocean environment, in contrast to the much more difficultly monitored practice of barging.

Construction materials for the piping in the system are still under study. Both interior and exterior corrosion (especially in the case of the undersea leg) make polymeric pipe attractive. In addition, their availability in long lengths and ease of joining and laying appears to be attractive. High density polyethylene and polybutylene and fiber reinforced polyester pipe would currently appear to be the most suitable materials of construction. Environmental stress cracking tests on a variety of commercial plastic pipe materials are now underway using solutions representing the waste compositions expected.

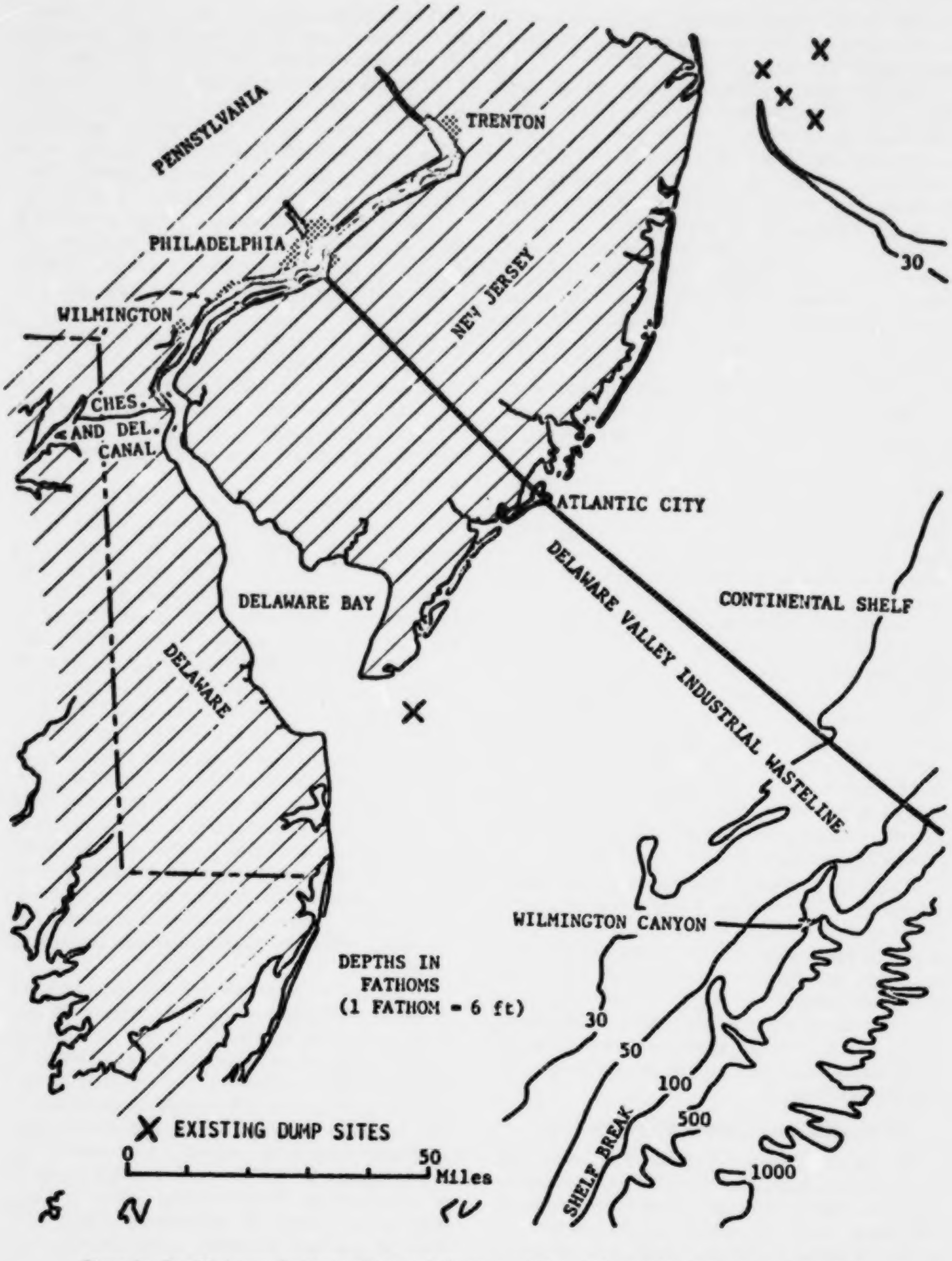
PENNSYLVANIA
TRENTON
PHILADELPHIA
WILMINGTON
NEW JERSEY
CHES. AND DEL. CANAL
ATLANTIC CITY
DELAWARE VALLEY INDUSTRIAL WASTELINE
CONTINENTAL SHELF
DELAWARE BAY
DELAWARE
WILMINGTON CANYON
DEPTHS IN FATHOMS (1 FATHOM = 6 ft)
X EXISTING DUMP SITES
0
50
Miles
30
30
50
100
500
1000
SHELF BREAK

Figure 3: Possible Layout for Regional Waste Collection and Disposal System for the Delaware River Basin

Pipe burial across the shelf would be carried out by hydrojetting to protect the line from disturbances by man and nature, since a life in excess of 20 years would be desired.

Ocean Studies

Long term seasonal studies on the currents, chemistry, and biology of the upper continental slope region are being conducted and will be reported on in detail at a later time. Less information on these three essential subjects exists for the continental slope area than for the shelf and near shore regions.

Preliminary indications are that on the continental shelf the general bottom current direction is westward to the shore.[3] However, on the slope the current direction is south-southwest (i.e., southward and parallel to the coast). Current velocities measured within a few meters of the bottom often exceed 1-2 knots; with occasional speeds greater than 2 knots.[4] Dispersion of wastes into the large body of water moving relatively swiftly in a south-southwesterly direction on the slope should result in relatively rapid dilution. It is generally known that assimilation in the ocean can occur as a result of chemical and biological action. This may be preceded by absorption on dispersed colloidal matter in the sea or in the wasteline itself (e.g., dredge spoils). Reasonable predictions on the disposition of the various waste components will be possible upon more complete study of the chemistry and biology of the region. Direct observations from the research submersible "Ben Franklin" indicated that a large volume of detritus and sediment already reaches the slope. Since many of the components in the wasteline are normal constituents in sea water, it would tentatively appear that upon dispersion the wastes would enter into the normal assimilative processes of the ocean. However, further studies will have to be made. Pending the outcome of these studies it would appear that the upper slope area with its deeper and offshore moving waters would be more preferable than either the shallow near-shore waters of the shelf itself or the deeper downslope waters where a thermocline exists. Below the thermocline life experiences less change, and is potentially less adaptable to change. In addition, temperatures below 4°C sharply reduce the rates of assimilation processes.

Legal Considerations

The legal aspects of constructing and operating such a waste collection and delivery system were examined by Professor Earl Finbar Murphy and Mrs. Ruth L. Kovnat, of the Temple University Law School; specialists in natural resource and internation law. It was concluded that there are no insurmountable state, federal, or international barriers to the concept. In addition, it was recommended that on the basis of existing statutes and with the intention of coordinating as many interested parties as possible, a public authority (i.e., interstate) form of organization would be better than a public utility of Federal authority.

Costs

An order of magnitude estimate for the capital cost of the point-to-point delivery system described in this paper would be approximately $100 million dollars. It should be recognized that exact estimates are not possible at this point, since we are in the middle of the feasibility study. Among the many variables that must be resolved more precisely are volume capacity, route, and technological design. The above estimate is based on the best recent cost data available for comparable overland and marine transmission lines.

Preliminary operational costs for transporting 16 mgd from the Philadelphia Region by pipeline to the upper continental slope 80 miles offshore appear to be on the order of $2 to $2.50 per 1,000 gallons. This compares quite favorably to recently published barging costs of approximately $4/1,000 gallons.[6]

REFERENCES

1. U.S. Army Engineer District Philadelphia, Corps of Engineers North Atlantic Division. *Long Range Spoil Disposal Study, Part V, Substudy 4, Pumping Through Long Lines,* June, 1969.

2. U.S. Bureau of Sports Fisheries and Wild Life, Sandy Hook, New Jersey. *The Effects of Waste Disposal in the New York Bight,* Interim Report for January 1, 1970.

3. Stanley, D. J. and Kelling, G. *Sedimentation Patterns in the Wilmington Canyon Area.* Transaction National Symposium on Ocean Sciences and Engineering of the Atlantic Shelf, Marine Technology Society, Philadelphia, Pennsylvania, March 19-20, 1968.

4. Halsemann, J. *Morphology and Origins of Sedimentary Structures on Marine Slopes,* Science, Volume 161, pp. 45-47, July 3, 1958.

5. The Franklin Institute Research Laboratories. *Proposed Delaware Valley Industrial Wasteline — Legal Implications — IDRES Information Center Report No. 1,* April, 1969.

6. Chemical Week, October 29, 1969, p. 75.

Land Application of Solid Waste

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INTRODUCTION

The application of land for the treatment of degradable solid waste is certainly one of the oldest methods. Perhaps we should take a second look at this older method, which over the years has filled the need for dependable treatment routes, at the same time adding modern advances in equipment and engineering to gain even more satisfactory operations.

Land application in this sense does not refer to the burial of waste as in a landfill, but the application of the waste to the topsoil. Various forms of spray irrigation, hydro-mulching spray, or shallow plow-furrowing of the topsoil are just a few of the schemes that have been employed to apply the degradable waste to the land. Treatment of waste in this manner has been particularly adaptable, although not restricted, to cheese factories, dairies, creameries, tanneries, slaughter houses, canneries, poultry dressing plants, and paper mills due to the large fraction of degradable organic solids in their respective waste streams.

This land application technique is used as a reference for the treatment of solid waste as Surface Composting. Actually this method of waste stabilization in the land is a crude form of composting, though strictly for waste treatment rather than for the production of a "valuable" compost end product. This approach to waste management is a unique biochemical process that must be well-planned and engineered to be a success for a suitable waste. Surface composting of putrescible and oxidizable components of solid waste is the treatment of these waste solids by applying them, either in solid form or mixed with waste waters, onto the topsoil of a prearranged site for stabilization. The stabilized, degraded in energy content, and rendered innocuous waste is the direct result of two basic natural soil phenomena, namely that of natural biological degradation of the organic materials by the action of the natural solid organism and the process of adsorption. Soil organisms in this instance refer to the various forms of microscopic life such as fungi and bacteria, molds, earthworms, and insects which feed either directly or indirectly upon the solid wastes. Initially, the largest percentage of degradable organic waste stabilization should be accomplished by the aerobic bacteria in the first few inches of topsoil. By the process of adsorption, the molecules of suspended as well as dissolved impurities are removed from solution by attaching themselves to particles of soil, clay, vegetation, and humus at or near the soil surface. The cation exchange capacity of the soil colloids is very important in the adsorption process because negatively charged colloidal particles attract and hold molecules of plant nutrients. The process of adsorption continues during cold weather when the activity of soil organisms is at a low ebb. Therefore, adsorption is of particular importance to a system operating twelve months a year.

The surface composting method most familiar to those in the waste treatment field is that of spray or furrow irrigation of diluted sewage sludges. This method was pioneered at Seabrook Farms in New Jersey in the 1950's and the initial installation was labeled a success. Immediately environmental engineers, sanitarians, and others faced with waste treatment problems considered this method as a panacea to all solid waste problems. This misconception led to many over-simplifications and inadequate engineering which resulted in the construction of systems which failed miserably.

The Engineering Process

To prevent, for example, such things as physically clogging the solid pores which causes a loss of infiltration rates and the build-up of layer after layer of non-stabilized waste creating anaerobic populations and nocuous odors, surface composting should be regarded as a process that must be technically planned and engineered to operate effectively year round. The type of waste in regard to necessary process parameters must be initially determined from pilot plant studies before construction of a major facility is initiated. Seasonal climatic variations must be weighed and evaluated in regard to their effects on the pilot process efficiency.

A properly designed and engineered surface composting process should be in compliance with the following:

Site Investigation

Preliminary Site Reconnaissance

1. Size and accessibility of location.
2. Nature and origin of the existing natural soils.
3. Nature of existing and potential drainage and erosion problems.
4. Position, source and history of both surface and ground water fluctuations.

Surface Soil Strata Investigation

1. Minimum test
    a. Classification test
    b. Permeability rates
    c. Types of microorganisms present
    d. Organic content
    e. Exchange capacity
2. To determine if a need for soil reclamation exists

Engineering Considerations

The Land

1. Solid waste and land interactions: it is known that a soil system is composed of gas, water, microorganisms, and minerals which form the solid matrix. A slurry of solid waste applied to the soil mixes with the existing soil and soil water becoming a part of the system, and may alter the nature and rate of change of the physical, chemical, and biochemical processes in the present soil system. Solid waste particles, such as suspended minerals, particulate organics, and inorganic precipitates are quickly filtered out of the moving liquid in the surface horizon of the soil. These substances are subject to alterations and degradation, but some of this material becomes a permanent part of the solid and may have a toxic inorganic salt accumulation on the cover crop (if present) as well as the existing soil ecology. Also, soluble constituents may penetrate deeper into the profile before interacting with the soil system, or they may pass through the soil profile relatively unaltered and reach subsurface water supplies. The waste may be high in monovalent cations such as sodium and ammonium which can displace divalent ions such as calcium and magnesium on the cation exchange positions in the soil matrix. Such exchanges can be detrimental to the properties of soils high in clay. All of the above soil-waste interactions must be studied and evaluated to determine the beneficial or detrimental changes occurring in the soil system in order to produce a successful surface composting process.
2. How much land will be required to achieve the desired waste degradation?
3. How much attention would the land require to insure adequate oxygen supply to the microbial reaction zone?
4. Drainage and erosion control must be engineered adequately in order to insure the useful life of the land being utilized.
5. Considering the type of waste and the surface soil, will nutrients have to be applied to accomplish the desired waste treatment?

The Waste

1. A thorough knowledge of the nature and characteristics of the waste composition must be known to even consider surface composting as a method of waste treatment.

Cover Crop

1. Is a cover crop necessary:

a. To hold and bind soil together as a check against erosion, depending on the slope and grade of the site terrain?

b. To increase the uptake of minerals from waste and by-products of soil microbial activity?

c. What plants are most desirable in relation to their tolerance of waste materials?

2. If a cover crop is required, how will it be harvested?

Application and Equipment

1. What is the optimum application rate without physically clogging the soil pores?

a. What waste concentration can be applied to achieve the desired rate of waste degradations?

b. Will the application rate have to be altered to correlate with seasonal changes in the weather?

2. What application technique and equipment should be employed?

a. Spray or furrow irrigation?

b. Shallow furrow plowing with an agriculture manure spreader?

c. Tank truck spray?

d. High pressure hydro-mulching injection spray with nutrients?

Economic Considerations

The Cost of Any Pretreatment of Waste Prior to its Application to the Land Such as Grinding or Shredding.

Purchase of the Land and Land Use Changes.

The Third Cost Would be That of Application Equipment Utilized and Maintenance of a Successful Process.

Environmental Pollution Consideration

Air

1. Would the evaporation of volatile organic materials create a nuisance and enhance smog formations?

Water

1. Will contamination of receiving streams result from runoff drainage?

2. Would ground water supplies become polluted by percolated leachates?

Ground

1. Will the soil become poisoned due to a build-up of inorganic salts?

2. Will the site become a nuisance and health hazard from a layer of non-stabilized waste on the land?

3. Will the site become unsightly due to massive populations of insects or rodents?

4. Would a health hazard be created from survival and movement of pathogens through the soil?

Case Histories

Gilde has reported that a Campbell Soup Company cannery located at Paris, Texas, has achieved a seventy to eighty percent reduction in both the COD and BOD of the plant's waste sludge from a spray irrigation process.[11] He further describes a cover crop of Reed Canary grass that was most desirable because it provided a protected habitat for soil microorganisms and a vast surface area for the absorption of organic impurities.

The Metropolitan Sanitary District of Chicago has successfully utilized sewage solids, as reported by Rose.[12] He describes a pipeline system that transports digested sludge to low quality land in Cook County and ultimately to land fifty miles south. He states that the spray irrigation of these wet sludges has resulted in healthy corn crops grown on prior nonfertile and poor quality land.

Morgantown, West Virginia, has a federal grant to pipe sludges five miles to a strip mine spoil area where it can promote regrowth of plant cover.[13]

Researchers at the University of California at Davis have reported that shallow furrow plowing of solid municipal refuse has demonstrated that the soil has a very great ability to assimilate the putrescible components of the refuse. In addition, they state that obtaining good mixture of the refuse with the soil was more difficult in the field than in the laboratory.

CONCLUSIONS

The organic materials added to the soil by the applied waste and the turned over cover crop increase significantly the soil fertility. In the formation of a fertile soil, these organic materials play an important role, as they are the source of plant nutrients such as phosphates, calcium and magnesium carbonates, and other compounds which are liberated in available forms by a root exudate (carbon dioxide and organic acids) and by various products of microbial activity. In addition, the added organic content has a fundamental effect on the physical properties of the soil (water holding capacity, heat regime), and determines to a large degree such physico-chemical properties as the exchange capacity and buffering properties.

The mineral content of the soil may be enriched slightly from the added inorganics from the waste applied to the land. Small additions of minerals may facilitate the growth of a very healthy aerobic bacteria population. Noncompressible inorganics would aid in the prevention of the compaction of the surface soil, thereby allowing increased oxygen transfer to aerobic soil microorganisms. In general, soil particles carry a negative charge, enhancing cation exchange processes in the soil. These added inorganic minerals will have a direct and important effect in determining various ways of negative charge formation. The production of humic acids from microbial decomposition of the organic waste have chelating or peptizing properties for inorganic waste minerals such as iron and aluminum. Movement of this uncombined iron and aluminum from the surface to the subsoil strata followed by possible destruction by anaerobic soil microorganisms of the organic chelates may be, in part, responsible for a future rich deposit of iron and aluminum oxides in these lower soil strata. Although an accumulation of inorganic minerals and salts can produce certain adverse effects such as an increase in the osmotic pressure of the soil solution; a rise in the proportion of sodium salts that supply sodium ions which absorb or fix on the surface of the clay particles in an exchangeable form; build-up of inorganic substances that can be toxic to the cover crop as well as the soil ecology, such as boron, chloride, molybdenum and some toxic heavy metals (arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, nickel, vanadium, zinc) either as soluble salts or "fixed" precipitated solids.

Another advantage of the surface composting process is that only the top soil strata is utilized, resulting in no future settling and shrinkage of the soil from future construction on the treatment site.

SUMMARY

The above beneficial aspects of land application of solid waste can be utilized most effectively in reclaiming stripped surface soil near abandoned surface mining operations. The adaptation of the environment in this manner toward the treatment of a suitable solid waste represents a least cost approach in order to obtain maximum waste treatment with maximum future land benefits. In this instance, suitable wastes become environmental assets rather than environmental polluters.

REFERENCES

1. Dunstan, G. H., and Lunsford, J. V., "Cannery Waste Disposal by Irrigation," *Sewage and Industrial Waste*, 27, 827, (July, 1955).

2. Dennis, J. M., "Spray Irrigation of Food Processing Wastes," *Sewage and Industrial Waste*, 25, 5, 59 (May, 1953).

3. Sanborn, H. J., "Disposal of Food Processing Wastes by Spray Irrigation," *Sewage and Industrial Waste*, 25, 9, 1034, (September, 1953).

4. Hunt, P. G., and Peele, T. C., "Organic Matter Removal from Liquid Peach Waste by Percolation Through Soil and Interrelations with Plant Growth and Soil Properties," *Agronomy Journal*, 60, 321, (1968).

5. Parsons, W. C., "Spray Irrigation of Wastes from the Manufacture of Hardboard," *Proceedings of the Twenty-Second Industrial Waste Conference*, Purdue University Extract Service, 129, 602, (1967).

6. Anon, "Disposing of Poultry Manure by the Plow-Furrow-Cover Method," *News and Views from the Bureau of Conservation and Environmental Science*, College of Agricultural and Environmental Science, Rutgers-The State University, New nswick, New Jersey, (1968).

7. Casa., L., and Surun, J., "Disposal by Spraying of Effluent from Agricultural Industries," Tech. Lait. (France), 20, 230, (1968); *Dairy Science Abstract* (British) 30, 527, (1968).

8. Leesment, H., "Irrigation with Dairy Waste Water," Svensk Mejeritian (Sweden), 59, 558 (1967), *Dairy Science Abstract* (British), 30, 30 (1968).

9. Bouwer, H., "Returning Wastes to the Land, A New Role for Agriculture," *Journal of Soil and Water Conservation*, 23, 164, (1968).

10. Dalton, F. E., Stein, J. E., and Lynam, B. T., "Land Reclamation - A Complete Solution of the Sludge and Solids Disposal Problem," *Journal of Water Pollution Control Fed.*, 40, 5, Part., 789, (1968).

11. Gilde, L. I., "Cannery and Poultry Waste Treatment," *Water Sewage Works*, 115, 338, (1968).

12. Rose, B., "Sanitary District Puts Sludge to Work in Land Reclamation," *Water Sewage Works*, 115, 393, (1968).

13. Engineering News Record, "Traveling Sludge," November 23, 1967, p. 22.

14. Hart, S. A., Flocker, W. J., and York, G. K., "Refuse Stabilization in the Land," *Compost Science*, II, No. 1, pp. 4-7, January-February, 1970.

Hydrologic Considerations in Sanitary Landfill Design and Operation

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The disposal of solid waste and incinerator residue by landfilling is of increasing concern because "choice" sites are disappearing, refuse is becoming more voluminous, and landfills are increasingly causing pollution, health, and nuisance problems.

This paper specifically considers hydrologic factors which control landfill leachate production. Leachate may be defined as the liquid which is discharged from a landfill to either surface or subsurface receptors (that is, surface or ground-water bodies). By this definition, leachate is not frequently visible. Therefore, a leaching landfill is not always obvious. The leachate may have a high chemical or biochemical oxygen demand, suspended and dissolved solids. The leachate may be generated within the landfill; it may be due to ground-water flooding the landfill; it may be caused by rainfall or surface water runoff infiltrating the landfill; or it may be due to a combination thereof.

A definition of the purpose of a sanitary landfill is necessary to place this paper in perspective. The classic purpose of a landfill is to provide a means for disposing of solid waste with minimum community disruption. The attitude most frequently associated with this purpose is, "bury it and forget it." A more realistic purpose is disposal combined with reclamation of man-made earth scars. This latter purpose implies a responsibility to control the disposal procedure in order to minimize disruption of the environment. It is the need to accept this responsibility that is (or should be) the impetus behind the studies of sanitary landfill behavior. Only when a genuine understanding of this behavior is attained will we be able to utilize properly and control sanitary landfills for disposal and, at the same time, fulfill our obligation to future generations.

Leachate Character

Do sanitary landfills produce leachate? This question is often asked and often difficult to answer. To provide an answer, two cases of leachate-producing landfills are presented. These landfills are currently under continuous evaluation by the Pennsylvania Department of Health in cooperation with Drexel University.

The first case is a landfill located in a ravine. The landfill is approximately 21 years old and has been inactive for less than a year. Figure 1 shows a continuous seepage, estimated at 10 gallons per minute, out of one of the landfill's faces. Leachate quality data for one test series is tabulated in Table 1. In Figure 2, a pipe is shown which goes

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under the landfill at the bottom of the ravine and carries a small creek from above the site. The pipe carries an estimated flow of 150 gallons per minute. Pipe joints are probably tight, as indicated by the relatively low pollutant concentration levels (Table 1).

The second case is a landfill located on a gently sloping hillside. The landfill is seven years old and has been inactive for three years. The seepage shown in Figure 3 is out of a side slope. Leachate analyses results are presented in Table 1.

These results show that landfills can produce a highly polluted, but extremely variable leachate.

Figure 2

Figure 1: Continuous Seepage Out of a Landfill Face

Figure 3: Seepage Out of Side Slope

TABLE 1
Character of Landfill Leachates, mg/l (except where noted)
Sample Date - February 5, 1969

	SITE A		*SITE B*
	Seepage	*Pipe*	
Estimated Flow (gal/min)	10.0	150.0	30.0
pH	4.9	5.6	5.6
COD	21,120.0	211.0	282.0
Suspended Solids	770.0	100.0	70.0
Total Residue	16,600.0	1,060.0	1,810.0
Hardness (as $CaCO_3$)	2,500.0	80.0	30.0
Potassium	920.0	50.0	110.0
Sodium	1 100.0	100.0	300.0
Iron	152.0	2.2	28.0
Chloride (free)	1,600.0	193.0	485.0
Sulfate	790.0	65.0	65.0
Nitrate	196.0	9.0	10.0
Nitrogen (free)	20.0	0.7	3.0
Nitrogen (organic)	1.1	0.0	0.7
Approximate Total Age (years)	21		7
Time Since Completion (years)	<1		3

Of particular interest are the factors influencing leachate quantity and quality, and what can be done to predict and control them.

Drexel University Study

The study presently underway at Drexel University is an experimental-theoretical analysis of the behavior of sanitary landfills. Only two portions of the study, the laboratory lysimeter and a moisture routing model, are discussed here. Details of the complete study are available elsewhere.[1]

Laboratory Lysimeter

In Figure 4, a schematic is presented of the laboratory simulated sanitary landfill, the lysimeter. The prepared refuse had an initial composition patterned after the results of Kaiser.[2] At time of placement, the refuse was eight feet thick with a two foot soil cover. The refuse dry density was 378 pounds per cubic yard, and the initial moisture content was 18.2 percent by volume. Thickness of the refuse has decreased since the initial placement. Temperatures at the bottom of the lysimeter are maintained at 57.2°F and top temperatures and water input are varied monthly, as listed in Table 2. Leachate is collected at the bottom of the lysimeter. Curves for water added and leachate collected are presented in Figure 5.

To discuss these curves, it is necessary to define three terms: (1) field capacity, (2) permanent wilting percentage, and (3) original moisture content.

Field Capacity

Defined here as the maximum moisture content which a soil or refuse can retain in a gravitational field without producing significant amounts of leachate.

Permanent Wilting Percentage

Defined as the moisture content below which moisture is unavailable for withdrawal by plants.

Original Moisture Content

The moisture content at time of placement. Usually, it is greater than the permanent wilting percentage. These curves show the influence of initial moisture content and the programmed feeding schedule on leachate production. The curves graphically indicate the initial lag between addition of water and production of leachate.

Substantial quantities of leachate can only be generated if each component of the landfill system (soils and refuse) is at its respective field capacity. In Drexel's study, the components of the landfill were placed in a relatively dry state. As a result, a major portion of the initially added water was adsorbed by each system component until each reached its respective field capacity. Adsorption is the cause for the difference between the two curves during the early portion of the test period. It is noteworthy that within one week after the initiation of the test, a small amount of leachate was obtained.

As the new quantity of water stored in the lysimeter increased, leachate production increased. A significant amount of leachate was produced by the system at approximately 430 days into the test. However, full system field capacity was not attained until the end of the reported test period.

The phase relationship between added water and leachate production is also evident from the curves. Even during periods of low leachate production, any decreases in water input further reduced or eliminated leachate. On the other hand, as water input increased leachate production also increased.

Moisture Routing Model

A model for evaluating the one-dimensional downward-vertical movement of moisture through a landfill has been developed. Water input is due to water infiltration on the free soil surface. The moisture routing procedure is based on the equation of continuity for prediction by hydrologic performance of any system component.[3]

Using this model, a soil-refuse system has been analyzed for four combinations of initial conditions. The system has a two-foot-thick cover soil layer and eight-foot-thick refuse layer. The cover soil has a field capacity moisture content of 0.349 on a volume basis and a permanent wilting percentage moisture content of 0.090 on a volume basis. The refuse has a field capacity of 0.286 on a volume basis and initial moisture content of 0.039 on a volume basis. The results of the analysis are presented in Table 3 for the environmental conditions listed in Table 2.

CASE 1 - **Emplacement of all materials at field capacity on January 1.**

When the components of the system are initially at their respective field capacities and the materials are emplaced during the wet season, leachate will appear immediately.

CASE 2 - **Emplacement of all materials on January 1 with the soil cover at permanent wilting percentage and the refuse at its natural moisture content.**

By emplacing the soil cover at its permanent wilting percentage and the

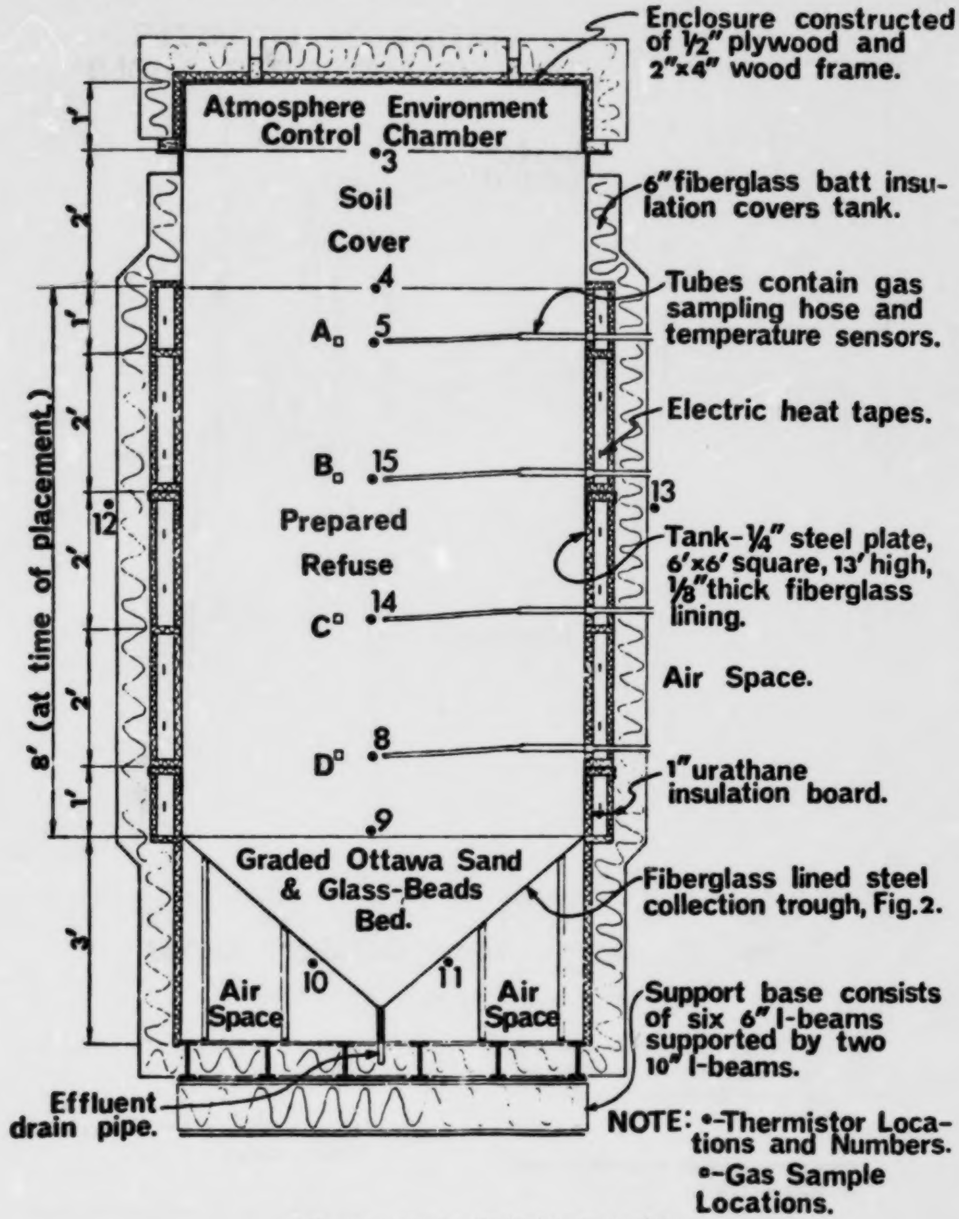
Enclosure constructed of ½" plywood and 2"×4" wood frame.
Atmosphere Environment Control Chamber
3
Soil Cover
4
A
5
B
15
Prepared Refuse
C
14
D
8
9
12
13
1'
2'
1'
2'
2'
2'
1'
3'
8' (at time of placement.)
6" fiberglass batt insulation covers tank.
Tubes contain gas sampling hose and temperature sensors.
Electric heat tapes.
Tank-¼" steel plate, 6'×6' square, 13' high, ⅛" thick fiberglass lining.
Air Space.
1" urathane insulation board.
Graded Ottawa Sand & Glass-Beads Bed.
10
11
Air Space
Air Space
Fiberglass lined steel collection trough, Fig.2.
Support base consists of six 6" I-beams supported by two 10" I-beams.
Effluent drain pipe.
NOTE: •-Thermistor Locations and Numbers.
▫-Gas Sample Locations.

Figure 4: Laboratory Simulated Sanitary Landfill

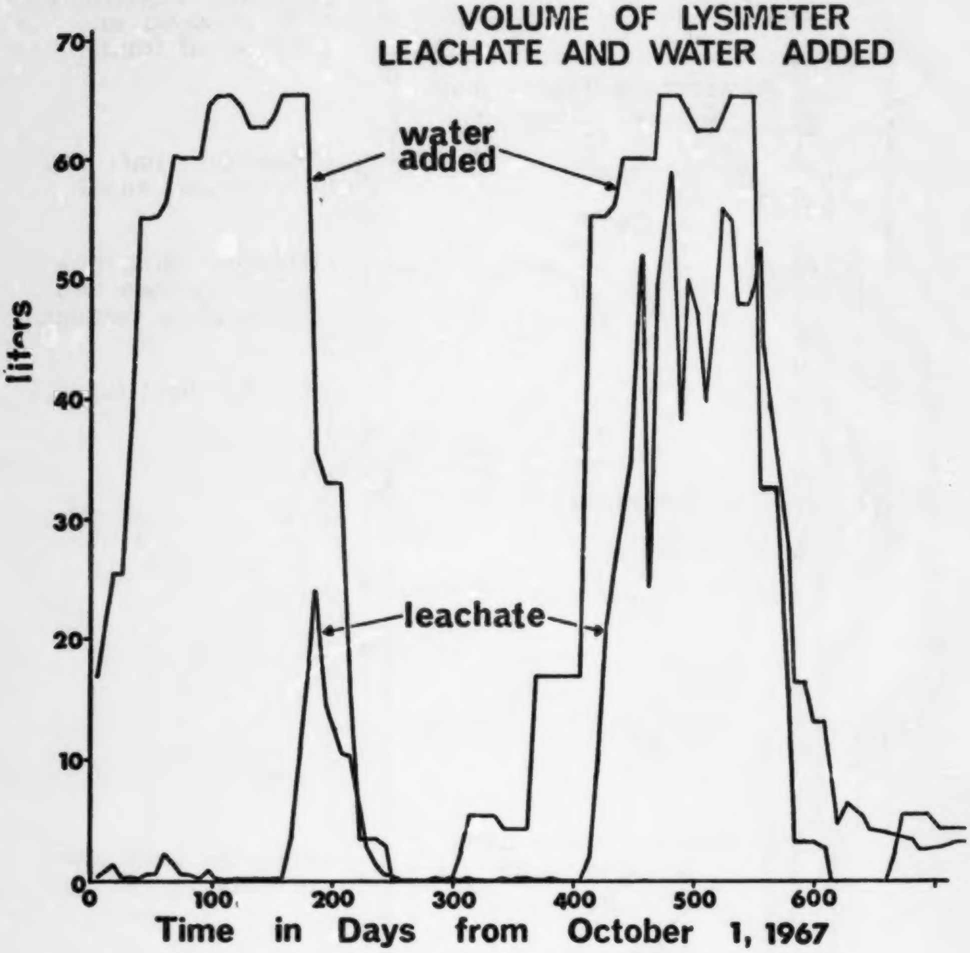

Figure 5: Volume of Lysimeter (Leachate and Water Added)

refuse at its initial moisture content during the wet season, leachate appearance can be delayed for thirteen months.

CASE 3 - **Emplacement of all materials at field capacity on July 1.**

When the components of the system are initially at their respective field capacities and the materials are emplaced during the dry season, leachate appearance can be delayed only until the beginning of the next wet season.

CASE 4 - **Same as Case 2, but with emplacement on July 1.**

By emplacing the soil cover at its permanent wilting percentage and the refuse at its initial moisture content during the dry season, leachate appearance can be delayed twenty months.

TABLE 2
Environmental Data for Southeastern Pennsylvania

Average Monthly Air Temperatures

Month	*Temperature °F*
January	33.4
February	33.8
March	41.3
April	52.1
May	62.7
June	71.4
July	76.0
August	74.3
September	67.6
October	56.6
November	45.1
December	35.1

Average Monthly Water Available for Infiltration

Month	*P-ET (Inches)**	*Gal/Month***
January	3.40	76,306
February	2.95	66,207
March	3.40	76,306
April	1.66	37,255
May	.18	4,040
June	-1.18	0
July	-1.85	0
August	.28	6,284
September	.21	4,713
October	.89	19,974
November	2.78	62,392
December	3.03	68,002

*Precipitation minus Evapotranspiration.
**Gallons per month on a 36-square-foot area. Water is added weekly.

The model has also been used to evaluate landfill behavior at eight different sites. The results are based on 30-year average rainfall and temperature data for the particular region. All the landfills have the same physical and environmental parameters as in the previous discussion. Results of this study are presented in Table 4.

Parameter Influence

Refuse Field Capacity

Figure 6 shows the results of field capacity tests on refuse. The top data points (squares) represent finely ground refuse. This refuse has an effective size of 3/16 of an inch. The data represented by the dots are for refuse ground to an effective size of one inch. Field capacity data obtained from other reported studies and the laboratory lysimeter are also shown.[4,5]

Type of Cover Soil

The influence of soil type is presented in Figure 7. The curves are based on experimental data.[6] The ordinates represent the time required to raise the moisture content of the soil from wilting to field capacity with a constant infiltration rate of one inch per month. The curves reflect the fact that as soils become finer, their field capacities approach a maximum while permanent wilting moisture percentages increase.

U.S. Potential Infiltration

The map in Figure 8 is a plot of average potential infiltration. This map is based on available rainfall and evapotranspiration data.[6] It is representative of conditions averaged over a year's period.

TABLE 3
Leachate Quantities (In Inches) From Kennett Square Sanitary Landfill for Four Different Emplacement Conditions

Case	*January*	*February*	*March*	*April*	*May*	*June*	*July*	*August*	*September*	*October*	*November*	*December*
YEAR 1												
1	3.40	2.95	3.40	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3							0.00	0.00	0.00	0.00	1.75	3.03
4							0.00	0.00	0.00	0.00	0.00	0.00
YEAR 2												
1	3.40	2.95	3.40	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
2	0.00	0.00	2.28	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
3	3.40	2.95	3.40	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
YEAR 3												
1	3.40	2.95	3.40	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
2	3.40	2.95	3.40	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
3	3.40	2.95	3.40	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03
4	0.00	0.00	3.27	1.66	0.18	0.00	0.00	0.00	0.00	0.00	1.75	3.03

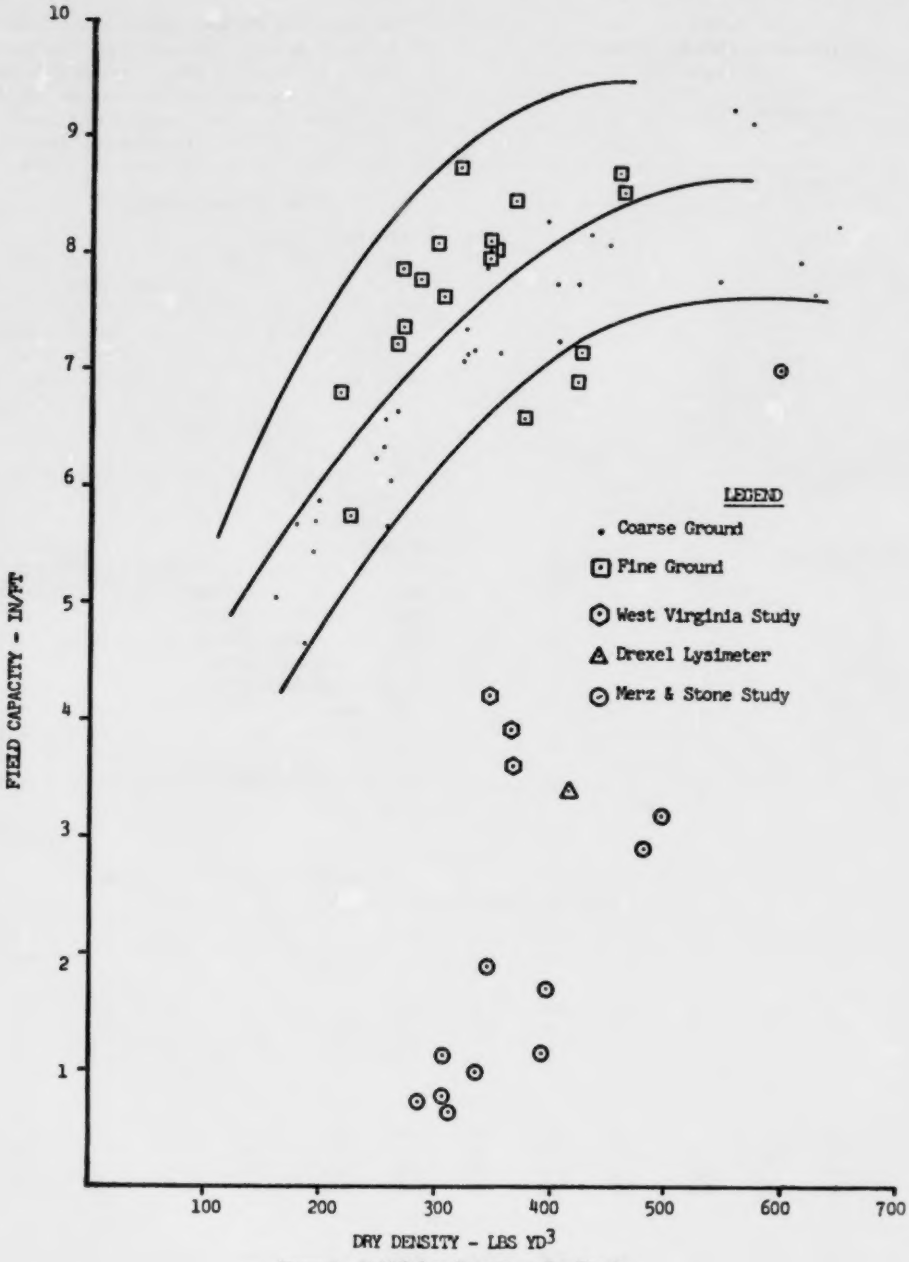

Figure 6: Field Refuse Capacity vs. Dry Density

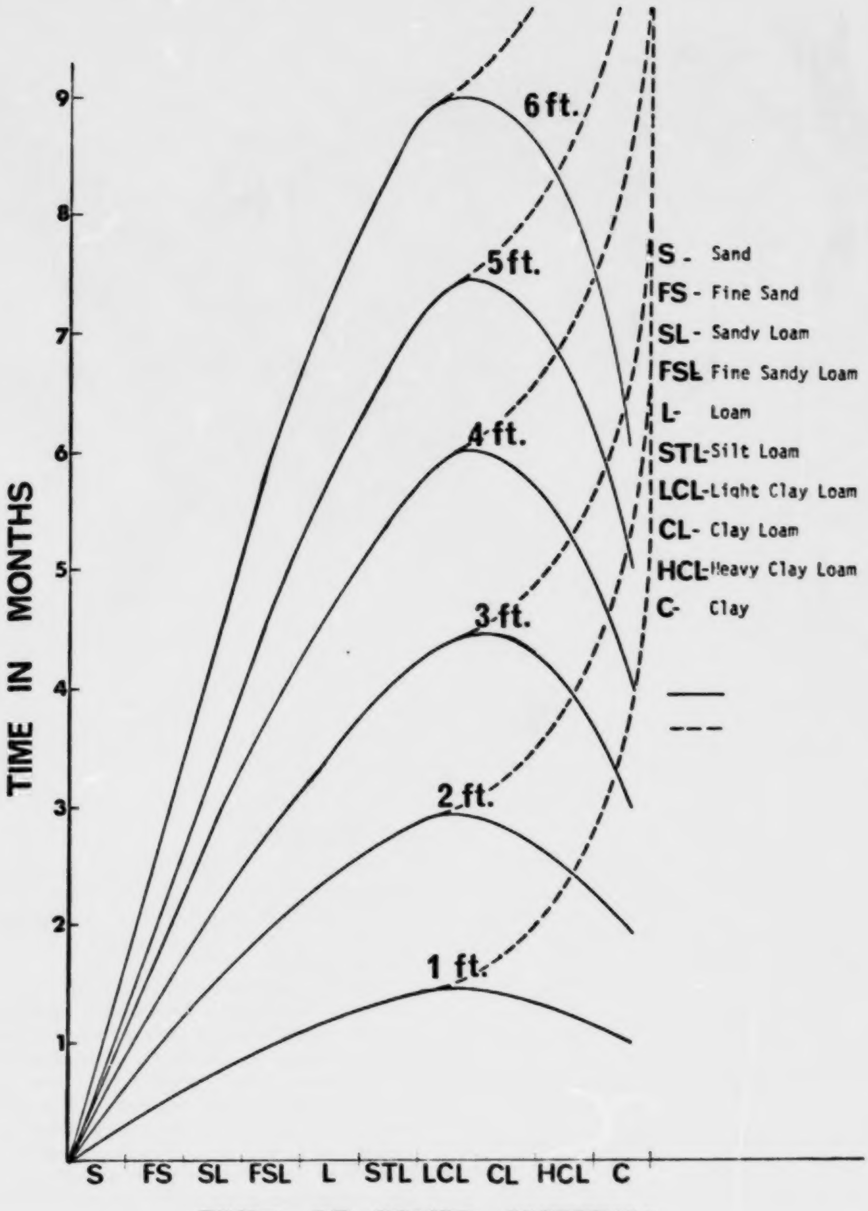

Figure 7: Time of Water Appearance vs. Soil Cover Type

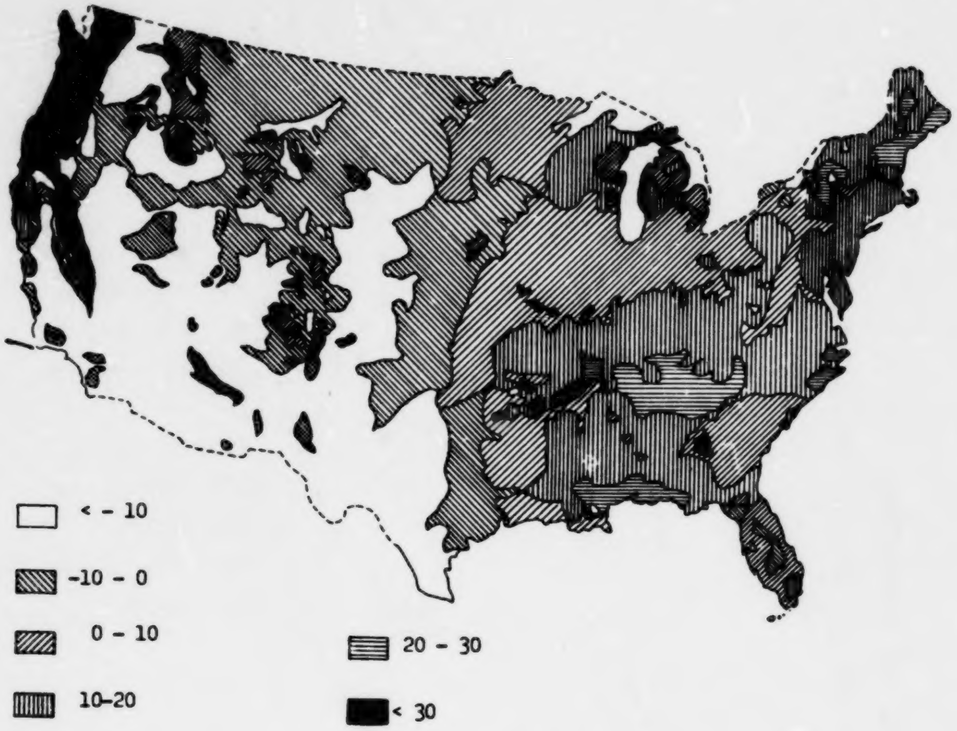

Figure 8: Average Potential Infiltration — Inches

TABLE 4
Computed Elapsed Time to First
Appearance of Leachate

City	*Elapsed Time in Months*
Wilmington, Delaware	24
Philadelphia, Pennsylvania	25
Mobile, Alabama	15
Sacramento, California	50
Los Angeles, California	145
Bismarck, North Dakota	∞
Riverside, California	∞
Phoenix, Arizona	∞

NOTES:

1. Based on average 30-year rainfall and temperature data for each area.
2. Refuse and Soil Data:

	Refuse	*Soil*
Field Capacity (in/ft)	3.49	4.18
Original Moisture Content (in/ft)	0.46	1.08
Depth (feet)	8.00	2.00

3. Placement date: October 1.

CONCLUSIONS

Most sanitary landfills have the potential for generating pollutant-carrying leachate. Leachate quantity depends on geographic location, surface drainage characteristics, and surface treatment, such as seeding.

Whenever the net water infiltration is positive, leaching is inevitable. Refuse field capacity increases significantly as refuse size decreases. With increasing dry density, the increase of refuse field capacity will asymptotically approach a maximum which is size dependent. Time of first leachate appearance can be greatly shifted by adjusting refuse and soil physical parameters and placement time. However, it is probable that placement time is not really controllable to any large degree.

Leachate production can be attributed to one or all of the following sources:

1. refuse compaction and placement,
2. channeling,

3. an advanced wetting front, and
4. the main wetting front.

Finally, because of their unique storage and behavior capabilities, landfills are able to develop mounds of water storage which locally raise the groundwater table. This is particularly significant where the hydraulic characteristics of the landfill system are very different from the surrounding soils, and where a local depression is filled.

REFERENCES

1. Final Report, "Pollution of Subsurface Water by Sanitary Landfill," to Public Health Serivce, In print.

2. Kaiser, E. R., "Chemical Analysis of Refuse Components," Proceedings, National Incinerator Conference, A.S.M.E., New York, pp. 84-86, 1966.

3. Remson, I., Fungaroli, A. A., and Lawrence, A. W., "Water Movement in an Unsaturated Sanitary Landfill," Journal of the Sanitary Engineering Division, A.S.C.E., No. SA2, April 1968.

4. Merz, R. C., and Stone, R., "Landfill Settlement Rates," Public Works, Vol. 93, No. 9, September 1962.

5. Quasim, S., "Chemical Characteristics of Seepage Water from Simulated Landfills," Dissertation, West Virginia University, 1965.

6. Russell, M. D. (Coordinator), "Water and Its Relation to Soils and Crops," Advances in Agronomy, Vol. 11, 1959.

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Technological Advances for the Industrial Processing and Utilization of Ferrous Materials

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There should be little doubt in anyone's mind that the word of the hour is "recycle." In the area of ferrous metallics, the Institute of Scrap Iron and Steel has been recycling the recycling concept for years. This need to conserve has been discussed with anyone and everyone who would listen.

But there were times when it seemed as if no one was really listening. However, on February 10, 1970, in his environmental message to Congress, President Nixon made one point which was quite clear when he stated, "I have ordered a redirection of research under the Solid Waste Disposal Act to place greater emphasis on techniques for recycling materials . . ."

It is unfortunate that our environmental problems have had to reach such critical proportions in order to arouse concern. In the area of solid waste, the third pollutant, it is interesting to speculate as to how much earlier this point of concern would have been reached, if there had been no salvage industries performing their recycling function. Some have said 30 years ago.

Often misunderstood and abused, mistakenly grouped under the tattered umbrella of junk men, the individuals of the salvage industry have taken society's discards, recycled them into the economy, and accomplished this as a part of the private sector at no expense to the taxpayer.

Some might say "big deal." For the iron and steel scrap processor it is a big deal. The days of preparing ferrous scrap with an ax are long gone, although there are many members of the Institute who began their yards in just that manner.

To enter the scrap processing business today on the same basis as existing factors requires a minimum investment of one-half million dollars. A baler capable of handling a whole car or a hydraulic guillotine shear to cut a car requires an average investment of about $200,000 installed. A shredding system begins at several hundred thousand dollars and some have cost as much as $3 million dollars.

By way of comparison, these dollar figures represent a lot of horse drawn wagons and axes. It would be interesting to know the thoughts of an old-time scrap processor who began his business with an ax as he watched a car being converted to fist size pieces of scrap by a giant shredder, or converted into a bundle the size of a console television set, or watched a guillotine shear slice through a slab of metal 12 inches thick.

In 1921, 9.1 million net tons of ferrous scrap was purchased by steel mills and foundries and 46,000 tons were exported. Our estimates for 1969 are 42 million net tons purchased domestically and 8.9 million exported — the biggest total year in the history of the scrap processing industry.

And while 1969 was a record breaking year, the industry was not operating at total capacity. Yet, the technological advances in equipment have made this capability possible. To say that we have reached the ultimate in processing equipment would be an unacceptable comment to you and to me. Equipment is no better than the market acceptability of the product which it produces. And any discussion of iron and steel scrap, sooner or later, must touch on the market, a free market which dictates when demand is down, price is down.

If any item is to be recycled, there must be a market for it. Discarded metallics, either as raw material or processed scrap which are sitting in a scrap processor's yard, have not been recycled.

It is unfortunate that many items which contribute greatly to the problems of metallic solid waste — consumer hard goods such as washing machines and refrigerators — do not all find their way to the scrap processor. The major reason is that markets for this type of material have not existed to absorb the quantity of material available.

A decline in markets which began in 1957 was a prime contributor to a breaking down in the collection system. The peddlers and collectors who had previously made a living by handling material which had been discarded on streets, in fields, or at dumps found it was no longer economically possible to perform this important function.

Metallic solid waste, which had once found its way back into the scrap cycle via the private sector, became a part of the total solid waste problem confronting local government. The collection system was severely shaken by a dramatic and tragic drop in the market for all scrap affecting particularly less desirable grades.

Even in the area of prompt industrial scrap — iron and steel scrap generated by industrial plants as a part of their manufacturing operations — there have been some grades which, until this recent surge in markets, generally had a negative value. Borings and turnings were not in demand, and as a result, many processors found it necessary to charge customers for their removal. In cases where manufacturers would not pay to have this material moved, and it must move, it was taken to dumps and landfills.

However, there has been significant progress in technology to make borings and turnings into a more saleable product. By taking what is an extremely bulking commodity and converting it into dense briquettes, this material has found its way back into the market as a desirable product. The challenge facing us all then is to find methods and techniques to keep obsolete metallics out of dumps and landfills.

Industrial scrap, with the possible exception of borings and turnings, is generally considered prime material. The major reason being that it is a known commodity — its chemistry can be readily identified and usually it is extremely clean. Although some of this material may move directly from the manufacturer to a consuming mill or foundry, the vast majority must go to the scrap processor in order to physically change the raw material to meet consumer specifications.

As one might expect, since the automotive industry is the largest consumer of steel, it is also the largest source of industrial scrap. Approximately 31 percent of the new steel which is purchased by auto manufacturers results in scrap. This material is sold on a monthly bid basis to scrap brokers or processors who either buy for their own account or purchase for the account of the steel mills or foundries they represent.

Unlike most other industry sources of industrial scrap, the majority of automotive plants have their own scrap processing equipment. These in-plant methods of handling scrap are without question the most sophisticated of any industry.

With the introduction of their new system, General Motors has gone one step further by taking the scrap from their metal stamping plants; cutting it into small pieces to be heated; and rolling it into sheets for use in car underbodies. Although the president of the Automobile Manufacturers Association feels that this process will mean that more obsolete automobiles will enter the scrap cycle because less industrial scrap will be available, some question his reasoning. Until more is known about the GM process, it is difficult to conceive of its being a significant contributor to the recycling of old cars.

In addition to industrial scrap being considered prime material is the fact that it must move. Unlike obsolescent scrap, which collects here and there and everywhere, industrial scrap, collecting at industrial plants in large quantities, cannot be allowed to accumulate. Generally, plants do not have the storage space. If it will not move to consumers at the market levels prevailing, then it will move into processors' yards to be held in inventory. If the processor finds that inventory or space prohibits him from taking the material, lesser grades, as a glut to the market, will again find their way to dumps and landfills.

At this particular point in time that does not seem to be the case. There has been a heavy demand for all grades of scrap these past few months, although indications are that the market is beginning to soften. Weather is certainly a factor since processing is an outside function which in many areas of the country means a slowdown in production during the winter months.

With scrap beginning to move in the spring, should market conditions reverse, we could face the problem just discussed — lesser demand for lesser grade of scrap. Some forecasters are of the opinion that continued demands by minimills will hold levels of scrap consumption, since electric furnaces, which are almost 100 percent scrap users, continue to grow in both numbers and steel output.

Nevertheless, the problem comes down to the advent of oxygen in steel-making. The introduction of the basic oxygen furnace and the gradual demise of the standard open hearth have curtailed the use of scrap by the big companies. Coupled with this is the tremendous expansion of the world iron ore sources and the continually growing impact of iron ore pellets. The overall result is that scrap has taken a severe beating in the market place, falling primarily on the obsolescent segment. And what is the single largest source of material from that segment? — the old automobile.

American scrap processors have the equipment and the technological ability to process every pound of material presented at their gates. There are about 75 shredders in operation in the United States with at least 10 more scheduled for installation this year. They have a capacity to process from 25,000 to 250,000 tons of scrap per year. There are approximately 500 guillotine shears and 1500 balers used to some degree for the processing of old autos.

The capability to keep pace with the increasing retirement rate of old cars and to clear up the backlog exists, but there must be a market for this material. The metallic solid waste problems facing our nation can be related directly to the demand for iron and steel scrap.

The complexities of the entire problem of effectively recycling metallic solid waste are such that the scrap processor alone cannot be asked to present the solution. If a solution is to be found, it will be necessary for consumers — steel mills and foundries — to work with the iron and steel scrap processing industry.

It is hoped that research will be undertaken to insure that meaningful progress is made in the total area of recycling metallics. We cannot afford to have our landscape littered anymore than we can afford to continue raping our natural resources. This nation was able to build the most advanced civilization ever known to man — our only hope is that we are smart enough to make it one in which we can continue to live.

Economic Factors and Technological Advances in the Industrial Processing and Utilization of Nonferrous Materials

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Last year 45% of the supply of copper in the United States, which to date was around 1.3 million tons, was recovered from scrap. What is perhaps even more startling is that for many years more lead has been recovered from scrap in this country than from domestic ores. And in 1969, during a disastrous strike of major Canadian nickel producers which shut off the flow of virgin nickel, it was the supply of nickel-bearing scrap - representing 15 to 20% of the total available supply - that kept U. S. consumers from closing down their plants because of lack of metal.

These capsule statistics dramatize the vital role that the $8 billion secondary materials industry plays in the economic life of this nation. The secondary metal industry has been recycling and reclaiming materials for more than half a century with growing efficiency, and greater technological know-how. It has built an economic bulwark out of materials that might normally have been discarded and cast out, and has developed an industrial pipeline through which such materials flow back into the mainstream of the American economy.

"Recycling resources" is the term our Association uses to define the activities of the industry. For these are indeed natural resources - raw materials vital to the industrial life of the nation. It is no wonder then that scrap metals have been aptly called "a mine above ground," comparable in every sense to the underground mines of ores and virgin metals.

In order to understand the actual flow of materials in a scrap plant, one should analyze the movement of scrap from source to consumer. Starting at the collection source, we have a vast flow of scrap materials from industry, government, farms, railroads, shipyards, etc. These move to either small scrap firms where a kind of basic sorting and segregating process is undertaken before moving on to larger scrap plants - or they are shipped right off to the larger plants.

At the scrap plant, the material is identified, sorted into different grades, and processed, - which means that it is cleaned, cut, sheared, and then packed by either being baled, bundled, or briquetted before being shipped to intermediate consumers.

These intermediate consumers are either secondary smelters, brass and bronze ingot manufacturers, refiners, brass mills, foundries, etc. From this point, the secondary product which is made from scrap finds its way to fabricators, brass mills, etc., or it is exported. With some variation, this is the actual flow of nonferrous scrap metals.

We represent a giant industry, one that can be classified with such industries as steel, petroleum, chemicals, and textiles. Like these, the secondary materials industry employs thousands of workers, has developed technical skills, has expanding markets in this country and abroad, and has built harmonious relations with its suppliers and consumers - but in addition, our industry has one quality that is not be found in all the others mentioned: it is a conservation and reclamation industry.

Scrap is an American product - collected, identified, sorted, and processed in the United States. We do not have to depend upon the import of ores and concentrates across thousands of miles of water, from countries whose political and economic instability may at any time cut off the supply, or which carry high ocean freight rates and are subject to tariffs and import duties. The sizeable savings in natural resources, and as a result, the efficient operations of the secondary materials industry are what help make our country a "have" nation as against other "have not" nations.

Last year we processed over 3 million tons of scrap metals in the United States. It is the recovery of these vast tonnages of scrap that assures domestic consumers sufficient supplies of raw material for their requirements. This lesson is always brought home with force during a critical strike, as the copper strike of 1967-68 when the flow of virgin metals was cut off and reliance on scrap was the only thing that kept domestic plants operating.

Our industry has a direct relationship with both producers of manufactured goods and the consumers of raw materials. From the back door of the manufacturer flows a vast accumulation of scrap destined for the plants and yards of the secondary industry. This so-called "industrial" scrap represents a major source of material handled by our industry. Other important sources are the following: shipyards, railroads, farms, households, sales by government arsenals and depots. Each year, millions of tons of nonferrous scrap metals move into plants of secondary firms to be collected, identified, segregated, processed, baled, briquetted, packaged, warehoused, and shipped.

To give you a specific idea of the tonnages of the various metals moved in a given year, the 1968 statistics show that over 1.2 million tons of copper scrap were recovered; more than 1 million tons of aluminum scrap; about 550,000 tons of lead scrap; some 254,000 tons of zinc scrap; and over 22,000 tons of nickel-bearing scrap; - as well as large quantities of such exotic metal scrap as titanium, molybdenum, tantalum; and precious metal scrap such as silver, gold, and platinum.

As a country produces more industrial goods, it generates more scrap. The aluminum industry, for example, which is a relatively new industry as metal industries go, is just beginning to reclaim the vast tonnages of aluminum scrap that result from obsolescence. At one NASMI convention, a leading aluminum spokesman declared, "Any material that has gone through a portion of the normal life cycle from its source, refining, and fabricating, has consumed a constantly increasing amount in labor, processing, and transportation expenses. The scrap industry is based upon the conservation of this value."

We cite this particular instance - although many more specific examples could be given - as part of the continued growth of the industry and its mounting importance in the economy. Today the field of scrap recovery is expanding into such areas as exotic and precious metals. A recent study indicates that the technology of secondary production is changing to permit a larger, much cleaner, and quicker recovery of the individual metals from scrap.

The reclamation and recycling of scrap should be considered as a central point in any discussion of future solid waste utilization. The secondary materials industry today is a modern, up-to-date, technologically sophisticated industry. NASMI, through its workshops, seminars, and meetings, constantly educates the industry in such areas as proper handling of equipment, training of workmen, improved yard and plant layout, and new processing techniques.

NASMI is in a good position to integrate and coordinate the recycling efforts of the secondary metals industry because, as an association, it represents both the processors of scrap and the consumers of scrap. Our membership includes both the hundreds of scrap processors who collect and prepare the large tonnages of nonferrous scrap in this country and the refiners, secondary smelters, brass and bronze ingot manufacturers, and even primary producers who recover this processed scrap and recycle it into the industrial mainstream.

Can you imagine what our cities and countryside would be like had not our industry pioneered and developed the means of collecting, processing, and utilizing secondary materials? Our industry has been and is becoming increasingly more important as a transformer of uneconomical "waste" into potentially valuable raw material. The challenge of the problem of solid waste will never be conquered without the implementation of the work of the secondary materials industry.

The secondary materials industries, not unlike any other business in the country today, are being subjected to a number of socio/political-economic forces that will require change on the part of the industry. Changing social values are having an effect on the ability of processors to obtain the necessary labor. The need for better pollution control is increasingly evident and results are being demanded. Additional economic forces which have an impact on the secondary materials industries include the following: the rising operating costs, import and export restrictions, and increased transportation costs.

Several years ago NASMI published a pamphlet entitled "The Secondary Materials Industries in a Changing Urban Society," in which we pointed out that urban renewal was having a disturbing effect on our industry. As old city areas were torn down to make room for new urban renewal projects, the scrap processing firms in these areas were dispossessed - but, unlike other firms, often could find no place to move within the city limits. Once they were out, it was difficult for them to relocate in areas adjacent to their industrial suppliers or their consumers. As a result, many small firms throughout the country have gone out of business. And yet these firms are the key to the collection program that leads to the utilization of solid wastes.

Another study by the association, "The Secondary Materials Industry and Environmental Problems," shows quite conclusively that within the past few years many cities have imposed restrictive measures through local ordinances in the zoning and licensing of secondary material concerns. These measures have had the effect of constricting the efficient activity of the scrap dealer.

Unless these local, state, and federal agencies become aware of the vital contribution of the secondary materials industry to the economy of the nation, their restrictive ordinances can only have a harmful effect on the collection of nonferrous scrap and, in the end, do a vast disservice to the industrial productivity of this country. Our association is attempting, through a widespread education campaign, to inform and make them aware of the function of our industry and of its part in supplying valuable raw materials. Without this secondary supply, metals would have to be imported from abroad at a higher cost to our consumers. And the solid waste problem would intensify.

Secondary materials move in international business: they are both exported and imported. The flow of scrap metals and other secondary commodities plays a vital role in the economic growth and stability of underdeveloped countries. Without these raw materials, many of these underdeveloped countries - lacking primary materials or the ability to pay for them - would suffer serious industrial handicaps. The larger nations of Europe and the Far East also are buyers of U.S.-generated scrap. As a result of this international trade, the U.S. also gains in balance of payments.

With the focus now on solid waste, one of the principal objectives highlighted by the Ad Hoc Committee on Solid Waste Management was "to economically recover and adequately process for recycling increasing portions of the solid waste stream."

The secondary materials industry has "economically recovered" material which might ordinarily have ended on the dump heap for over half a century. It has converted "waste" into useful raw materials valued at billions of dollars. Through its ingenuity and technology, the industry has developed new scientific processes of separation, processing, and packing in order to market secondary materials more economically.

The operations, methods, and techniques used in modern scrap plants are based on the latest principles of mechanization and automation. To compare these to the manual handling of scrap in days gone by is to compare the flight of Apollo 10 to that of the Wright Brothers!

There was a time, not too long ago, when the industry might have been self-conscious about the use of such words as "technology." Today, it not only takes such concepts in its stride, but it also moves with assured sophistication into fields of research and development, physical and chemical analysis, advanced materials handling processes, computerization, and air pollution systems. And why not? As an $8 billion industry, it is the repository of tremendous raw material resources vital to the economy of this nation.

With the continued advancement of the industry — and the secondary materials industry may be defined as a "growth" industry — extensive expansion plans are being made to handle the ever larger volume of raw materials flowing into the nation's scrap plants and yards. This means the need for increased plant space, yard layout based on materials flow, laboratory facilities for identifying and analyzing the various grades of scrap, up-to-date materials handling equipment, and new methods to package the end-product as it moves to consumers.

The technology of the scrap industry today has to meet the multiplicity of scrap grades which have emerged in the past few decades. Many of these grades — particularly in the field of nickel alloys and exotic metals — are unusually complex and require special analysis to identify them. Special analytic equipment has been devised to make identification more accurate for these complex alloys. Not only the machinery and equipment, but also the labor force itself must be expertly trained for this complex work.

To those who may not have a true image of the scrap industry as it operates today, a recent profile survey by our association offers some very interesting factual data:

- Approximately 41% of association firms have multi-plant operations. (The average is over 2.5.)
- The "average" association member employs 13.4 executive and supervisory employees and 77.5 plant workers. The "average" firm payroll is over $500,000.
- More than half of the association's firms have an annual gross sales in excess of $3,000,000, and the membership average approximates $10,000,000.
- More than half of the association's members value their capital investments in plant and equipment in excess of $500,000 and the average is $1,300,000. The total valuation placed on plant and equipment of just the association's member firms is over $700,000,000.

Ours is a technologically-oriented industry which is always on the lookout for improved techniques to help it bale and pack its merchandise, upgrade it in value, remove contaminants, eliminate pollutants, and find ways and means to reduce processing costs. At the same time we are not content with existing markets but must find new outlets through technical developments. It is the knowledge and expertise derived from the latest technical advances that makes the secondary materials industry the focal point of the recycling of aw materials in this country.

For many years, the recovery of copper from insulated wire — a large tonnage operation — was accomplished through a simple method known as "open burning." That is, the insulated wire was usually taken into an open field or open area where the insulation was burnt off. As air pollution laws became more stringent, this technique had to be abandoned and it is today totally obsolete.

The next step was to develop adequate incinerators which would be able to house the burning off of the insulation while eliminating the air pollution. This type of "controlled burning" under specifically devised conditions to reduce or eliminate the smoke hazard through use of afterburners is being used with varying degrees of efficiency.

However, the industry realized that even incinerators are not the last word on the subject, and continued research led to the invention and use of the so-called wire choppers and mechanical separator. These devices cut the wire into very small segments and, by various methods, remove and separate the insulation from the copper wire. A number of companies in the industry utilize specific methods, each different from the other, but the mechanical separation process has become increasingly popular. It is concrete evidence of the type of research that is going on continually within the industry.

While this is perhaps one of the more dramatic developments, there are other advances being made which lead to more scientific reclamation and processing. To help identify metals, several types of portable equipment have been developed. The metalscope uses the following principle: Standard spectrograms of pure elements and the more common metal alloys are recorded on special mylar film built into the unit. The spectrolines from the sample are projected in their true spectral colors adjacent to the standards which are also seen in their true spectral colors. The lines are then compared and matched on a side-by-side basis for positive identification.

Another type of automatic metal identifier is the sortometer. This device operates on the thermo-electric reading generated at the heated junction of two dissimilar metals. Calibrated lists for almost all metals are provided with means for easy and quick metal identification.

Large shears are now a common site in almost every secondary plant, some of the blades going up to a length of almost 20 feet. Here again larger equipment can reduce the handling cost and thereby allow the dealer a more efficient operation.

Automatic briquetters that are capable of ejecting briquettes at the rate of 150 per minute are not an uncommon sight. This equipment reduces the volume of material that is to be shipped and transported to a fraction of its former volume, thereby reducing handling and transportation costs. Equipment and inventions of this type, in many cases developed by the secondary metal dealer himself, have gone a long way to bring sophistication to the secondary materials industry.

The problem of air pollution also affects the operations of the secondary metal industry. Here, too, companies in our industry are taking advantage of the latest and newest scientific technical advances in order to help solve a very critical problem. There are numerous approaches, and one of the first-and perhaps most obvious-is the collection of fume and smoke through the medium of collecting hoods and duct work and passing these gases through a cleaning device. This cleaning device could be any number of pieces of equipment such as after-burners, electric precipitators, or wet scrubbers. All of these devices are becoming more efficient and more adaptable at affordable costs. A second way that our industry has decided to combat the air pollution problem — that is effective in some cases but not in all — is in the redesign of the furnaces and processes that are used in the smelting and refining industry. In one specific industry, the refining of copper, a new furnace has been developed that is of the reverberatory type and operates in an atmosphere of almost 100% oxygen. The amount of pollutants that this type of furnace gives off is only a fraction of that normally given off by most furnaces used by copper smelters.

Industry members take the view that sometimes it is better to invest $200,000 in a new furnace and new design than it is to invest $100,000 in air pollution equipment that must be maintained and operated from then on. So, as you can see in the examples pointed out, the secondary metals industry has successfully solved two problems in an economical manner and has continued to be able to recycle the products that are so very much needed by our economy.

In order to maintain a uniform quality control, NASMI drew up specific standards and classifications covering various categories into a set of specifications for nonferrous metals. The current standard is "Nf-66," an outgrowth of standards established over 50 years ago. In it are 120 different classifications for nonferrous scrap metals. Each one is word coded and numbered. These standards are of tremendous help to both buyers and sellers of scrap metals. A buyer who is located in California can be sure he is talking about the same product when dealing with someone in Virginia and they are discussing "New Nickel Scrap" Code #82 or "Old Nickel Scrap" Code #83. These standards clearly set forth each category as to content and allowable contaminants. They eliminate potential problems for both the buyer and seller.

Like the primary metals industry it so significantly supplements, the secondary metals industry has a vast potential in the economy of the future. But beyond this economic importance, the secondary industry uniquely serves as the primary force for raw material conservation and solid waste utilization. It alone can recycle ever-mounting tonnages of solid waste to existing markets and develop new utilization outlets. Secondary metals are a national asset which the United States is fortunate enough to possess and which must not be dissipated. Communities, states, and the federal government must find new ways to encourage scrap consumption. They must foster favorable conditions for the secondary metal company. Prejudices and restrictions must be minimized so that solid waste utilization can be maximized. Our industry, our association stand ready for a major, national effort. *Recycling resources* — that's our business, and it is with this concept — a concept that embodies conservation, maximum utilization of materials, and a commitment to reducing the solid waste problem-that we approach this decade with the determination and confidence to accomplish our objectives.

Refining of Ferrous Metal Reclaimed from Municipal Incinerator Residues

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INTRODUCTION

The Bureau of Mines has developed a successful system for separating incinerator residues into major components. The magnetic or ferrous fractions normally comprise 30 to 35 percent of the total residues. Because of slag and metal oxides adhering to the iron surfaces, the actual iron content of the residue is 20 to 25 percent. This potentially represents the major value. At current prices for high-grade steel scrap, this iron commands about $40 to $45 per ton.

During incineration, the iron and steel become contaminated by other elements, most notably copper and tin. The copper probably derives from copper wire and copper alloys in contact with the iron at incineration temperature, and the tin is introduced from the tin-coated steel cans. Typical ranges for these elements would be 0.2 to 0.5 percent copper and 0.1 to 0.4 percent tin.[1] These elements have a deleterious effect on the physical properties of steel for some uses. Consequently, steel producers have not indicated any interest in this scrap. This paper describes the nature of the copper and tin in the ferrous material and methods which have been used to remove these residual elements.

While there does not seem to be any absolute limit on copper and tin levels for steel, private communications with people in the industry have indicated probable acceptable levels. From the best information available, the maximum levels to be attained have been set at 0.10 percent copper and 0.06 percent tin. It is anticipated that the iron scrap product refined from incinerator residue will meet the requirements for electric furnace feed.

Nature of Ferrous Fraction

Several tons of incinerator residue have been obtained from a number of incinerators in the United States and processed in the continuous unit at College Park. One of the products from this process is the +4 mesh magnetic material from which the copper and tin are to be removed. Most of this is cans with some wire and other miscellaneous configurations. With much of the slag and surface oxides removed from passage through the shredder, the nonuniform distribution of copper on the iron surfaces was very noticeable. In most cases it was present as a thin film or as small globules; in a few cases a copper-based part was mechanically attached to the iron, e.g., an iron nut on a brass bolt.

The nature of the tin on the steel surface is more complex than that of copper. Cross sections were taken of typical cans from several incinerators and subjected to a microprobe study. Line scans were made by moving the samples under the electron beam perpendicular to the metal at a specified rate. Tin and iron X-ray intensities were recorded simultaneously on a chart recorder. An example is shown in Figure 1. Wide differences in diffusion were noted among the samples and even from one side of the metal to the other. Diffusion of tin up to 1 mil in depth can be seen on both sides. When intensive diffusion occurred, free tin or tin-iron compounds were absent. They are likely present, however, when limited diffusion has taken place. One scan in the study showed about the right amount of tin and iron to be FeSn.

X-ray spectrography indicated that Sn and SnO are present on some samples, but SnO_2 and tin-iron compounds, if present, did not exceed 3 percent.

Sampling for Analysis

To determine the amount of copper and tin in the ferrous fraction, several lots of at least 1 lb. were taken and smelted individually in a 20-kw induction furnace. Coke and flux ($Na_2CO_3Na_3B_4O_7$) were added during the smelt. The molten metal was chillcast, and random drillings were taken from the ingots for chemical analysis. The following table shows the copper and tin levels in the ferrous fraction from four incinerators.

TABLE 1
Ingot Analyses

Incinerator	*Pct Cu*	*Pct Sn*
A	0.32 ± 0.11	0.18 ± 0.02
B	0.21 ± 0.03	0.25 ± 0.05
B1	0.15 ± 0.04	0.18 ± 0.01
C	0.22 ± 0.20	0.23 ± 0.06
C1	0.39 ± 0.32	0.15 ± 0.02
D	0.09 ± 0.05	0.14 ± 0.01

Samples B and B1 were obtained from the same incinerator several months apart; samples C and C1 are from two processing runs performed on one large sample of residue.

Selection of Extractive Processes

Copper

The copper which contaminates the ferrous fraction has been previously described as surface copper. The best process for its removal should entail copper dissolution with no concurrent iron dissolution. An ammoniacal-ammonium carbonate solution, which has been used for copper hydrometallurgy, seemed ideal for this application.[2, 3] The chemistry for the extraction of copper by this method is shown by the reaction:[4, 5]

$$Cu + 1/2O_2 + 4NH_3 + H_2O \longrightarrow Cu(NH_3)_4^{++} + 2OH^- \quad (1)$$

The copper content can be built up to about 30 gpl, at which time steam distillation of the pregnant liquor precipitates essentially all of the copper as CuO. The ammonia and carbon dioxide which have been stripped from the solution are recovered and recycled in the process with little loss.

Tin

Because the tin is present in a diffusion layer on the iron surface, the problem of tin removal is more difficult and will most likely involve simultaneous removal of iron. In addition, the presence of Sn, SnO, SnO_2, and possibly tin-iron compounds may necessitate the use of several extractive agents. Experiments were conducted with many compounds, such as chlorides, sulfates, hydroxides, fluorides, silicofluorides, and combinations thereof, either as molten fluxes on the iron surface or in contact with the molten metal. Aqueous leaching using sulfuric and hydrochloric acids and hot $NaOH-NaNO_2$ solutions was also tried.

Experimental Procedures

Copper

A rotary drum leach tank, 19 in. by 14 in. and about 14 in. deep, was used for leaching copper. The 12 in.-diameter drum, driven by a 1/8-hp motor with variable-speed control, rotates on its axis in the tank. The inside of the wire screen drum has three equally spaced baffles for tumbling the charge. For good agitation, the drum was about half filled with charge. A plastic cover on the tank prevented loss of ammonia during operation. A rubber tube connected to the hole in the bottom of the tank allowed sampling and served as the drain at the end of the run.

Some tests were conducted in upright transparent columns 6 ft. high with a diameter of 5 in. The charge remained stationary, but the solution was continuously pumped at variable rates out of the bottom and into the top of the tube. Test conditions in column leaching were varied essentially the same as in rotary drum leaching except that 8 to 10 liters of solution were used. Flow rates varied between zero and 1000 ml/min.

The initial phases of the work studied the effect of variables such as time, temperature, ammonium ion concentration, $[NH_3]/[NH_4^+]$ ratio, aeration, and additives on the rate of copper removal. Depending on the bulk density of the charge, 5 to 10 lbs. were used with 10 to 15 liters of solution. Fresh solution was used for most of the runs. The drum was rotated at 17 RPM for up to 24 hrs. Small samples of solution were periodically withdrawn and analyzed for copper. From these data, rate extraction curves were constructed for analyzing the effects of variables.

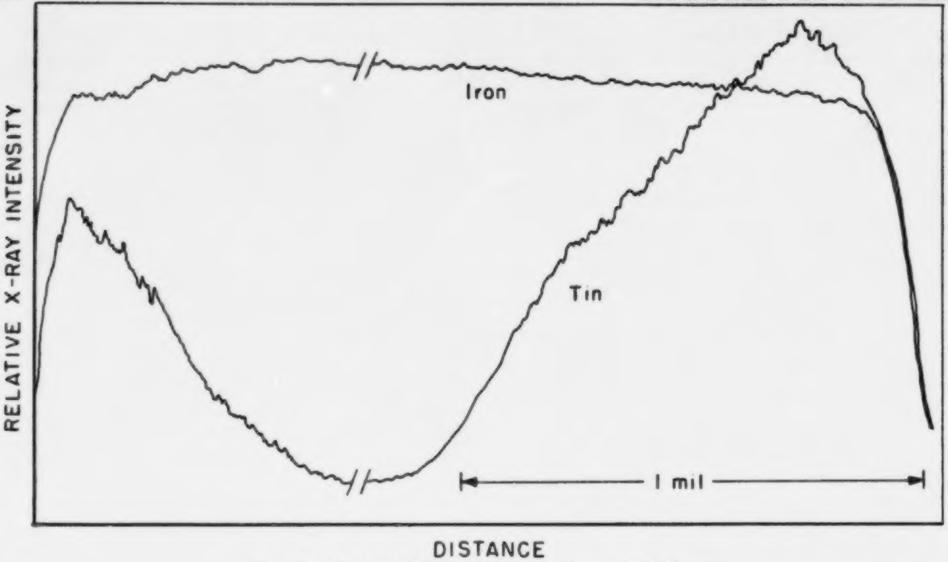

Figure 1: Line Scan of Cross-Section of Incinerated Tin Can

The standard leach solution was composed of 34 grams per liter (gpl) of ammonia, added as ammonium hydroxide, and 26 gpl of ammonium carbonate. Variations of these amounts were tested, as were additives such as hypochlorite, chlorate, peroxide, and persulfate. Temperatures above ambient were maintained by using heating tapes attached to the bottom of the leach tank.

At the conclusion of the run, the solution was drained and sampled. For some selected experiments, the sludge was collected and dried for analysis. The iron product was washed with water, dried, weighed, and smelted. Material balances for copper and tin were made to determine the extent of copper removal in the solution and possible tin removal in the sludge from abrasion.

Tin

One of the methods investigated for extracting tin was surface fusion by coating and roasting. For best coating results, the metal was dipped into a hot, concentrated slurry or solution of the reagent for several minutes and then dried in the oven at 110°C. This produced a uniform, adherent coating over the entire iron surface, the coating comprising from 10 percent to 50 percent of the charge weight. The charge was placed in clay-graphite crucibles and heated in a 5.5-kw box-type furnace. Temperature was controlled by a thermocouple positioned in the middle of the 18-in. cube compartment. After roasting was completed, the crucible was removed from the oven and either air cooled or water quenched. In most cases, a water wash of the material was followed by washing in dilute HCl solution and agitated with a brush to enhance scale removal from the iron surface. The solutions and wash residues were analyzed for tin along with the smelted ingot.

In addition to the removal of the tin from iron in the solid state, some experiments were performed on molten metal in clay-graphite crucibles in the induction furnace. The reagents were either coated on the charge before melting or they were added to the charge during heatup and after the iron became molten. The metal was kept molten for 5 to 10 minutes, after which time it was cast into an ingot and sampled. The slags were also analyzed for tin, but no attempt was made to trap and identify any volatile tin compounds in the fumes.

Another method was aqueous leaching, which included solutions of NaOH, HCl, and H_2SO_4 using 1- to 4-lb charges of ferrous material in laboratory beakers. Tests were conducted for up to 72 hours at 95° to 105°C for NaOH solutions and at room temperature for the acids. The solutions were analyzed for tin at the conclusion of each test; no rate studies were made.

Results

Copper

Ten pound samples of the ferrous material from Incinerator A were processed in the rotary drum leach tank to determine the conditions for best extraction efficiency. Selected results are shown in Table 2. In 6 hours at room temperature, the best extractions were achieved using chemical oxidizing agents. The extractions were calculated with the assumption that the amount of soluble copper available for extraction was in excess of the 0.06 percent copper that was alloyed in the original base metal itself. Since under these conditions the maximum extraction was 56 percent, further work was done at higher temperatures and longer time in an attempt to achieve 100 percent extraction. The standard leach solution was used in these experiments. Temperature did not appear to affect extraction significantly, but extension of the leach time did increase extraction to 78 percent. The use of hypochlorite, chlorate, or persulfate did not appear to offer any advantage when the leach was conducted for 24 hours at about 55° C. Extraction efficiency of 100 percent was attained with hydrogen peroxide.

Another indication of extraction was the rate at which the copper dissolved under different conditions. The rate curves for these runs, one of which is shown in Figure 2, exhibited breaks during the first 1 to 3 hours. This break is interpreted as the end of the dissolution of the thin copper film with high area to weight ratio. From then on, the dissolution rate is controlled by the more massive copper areas. Hence, surface area is probably the most important variable in the process, and the one that cannot be measured. An indication of surface area from the initial rate of reaction, expressed as mg Cu hr^{-1}, can be seen in the last column of Table 2. Comparison of these data indicates that oxidizing additives and higher solution temperature are conducive to faster reaction rates which should translate into higher extraction efficiencies, all other factors being constant.

Extraction curves from the column leaching method on iron from Incinerator C are compared to those from the rotary leach tank in Figure 3. The flow rate through the columns was 900-1000 ml/min. Part of the wide discrepancy in the results is due to the variation in copper content, as given in Table 1. Column leaching exhibited lower extraction rates than rotary leach and hence, necessitated much longer leaching time as indicated by the flatness of the curve beyond 15 to 20 hrs. The advantage of the rotary leach is the continuous abrasion of the iron surface to expose the copper that may be hidden by slag or surface oxides. In addition, about 3 percent to 7 percent of the tin is removed as part of the sludge.

Since the rotary drum leach tank offered the best means of extracting copper, ferrous fractions from other incinerators were tested in it using the standard solution at room temperature. To conserve materials, the previous leach solution plus makeup was used for each succeeding test. Figure 4 shows four typical rate curves derived for four charges from Incinerator B. This ferrous fraction-composed mainly of tin cans-was obtained directly from the on-site shredder at the incinerator. The similarity in the initial rates would suggest that the nature of the copper on the surface is very similar and uniform and that the only difference is in the amount present. In all cases, the copper was removed in less than 12 hours; and in most cases, only 8 hours were required.

TABLE 2
Effect of Leaching Variables on Cu Extraction

			Leach			Pct Cu			
NH_3, gpl	$[NH_4]_2CO_3$, gpl	$[NH_3]/[NH_4^+]$ wt. ratio	time, hr.	temp., °C	Additive	residual	calculated in charge	extracted	Initial reaction rate, mg Cu hr^{-1}
17	13	3.5	6	R.T.[1]	None	0.36	0.40	23	1212
34	26	3.5	6	R.T.	None	0.22	0.38	56	1670
60	26	6.2	6	R.T.	None	0.13	0.16	42	246
34	46	2.0	6	R.T.	None	0.27	0.34	42	704
34	26	3.5	6	R.T.	Air	0.16	0.20	40	915
34	26	3.5	5.5	R.T.	NaOCl	0.28	0.45	51	3600
34	26	3.5	6.5	R.T.	$NaClO_3$	0.18	0.28	55	1300
34	26	3.5	6.5	R.T.	H_2O_2	0.24	0.41	54	8000
34	20	3.5	6	R.T.	$(NH_4)_2S_2O_8$	0.41	0.57	41	280
34	26	3.5	6.5	55	None	0.44	0.60	38	2700
34	26	3.5	24	54	None	0.12	0.29	78	1500
34	26	3.5	24	54	NaOCl	0.17	0.36	69	N.D.[2]
34	26	3.5	24	55	$NaClO_3$	0.19	0.46	73	N.D.
34	26	3.5	24	55	H_2O_2	0.06	0.23	100	N.D.
34	26	2.9	24	47	$(NH_4)_2S_2O_8$	0.11	0.34	86	N.D.

[1] Room temperature.
[2] Not determined.

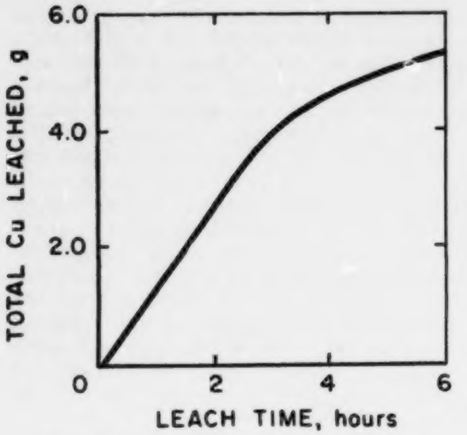

Figure 2: Leach Curve from Test Using Na, Cl, O_3

In Figure 5 are plotted some typical rate curves to illustrate the differences between ferrous fractions from several incinerators. Tests 2 and 7 used material from Incinerators C and B, respectively. These incinerators are considered relatively efficient since they burn at higher temperatures and very few, if any, combustibles are found in the residue. The difference in rate between these two is probably due to the nature of the shredded ferrous material. Material for Test 2 was shredded in the laboratory unit which has a tendency to ball the cans. Material for Test 7 was obtained from an incinerator which shreds its ferrous fraction for use in industrial copper cementation. Therefore, this material has open surface area and less surface slag and oxides. Material for Test 8 was obtained from a relatively inefficient incinerator and shredded in the laboratory. Apparently the temperature of this incineration was low enough to prevent the melting and brazing of copper onto iron surfaces.

Tin

Aqueous leaching was tried initially. Solutions of NaOH, as used in commercial detinning operations, gave very little extraction. Sulfuric acid

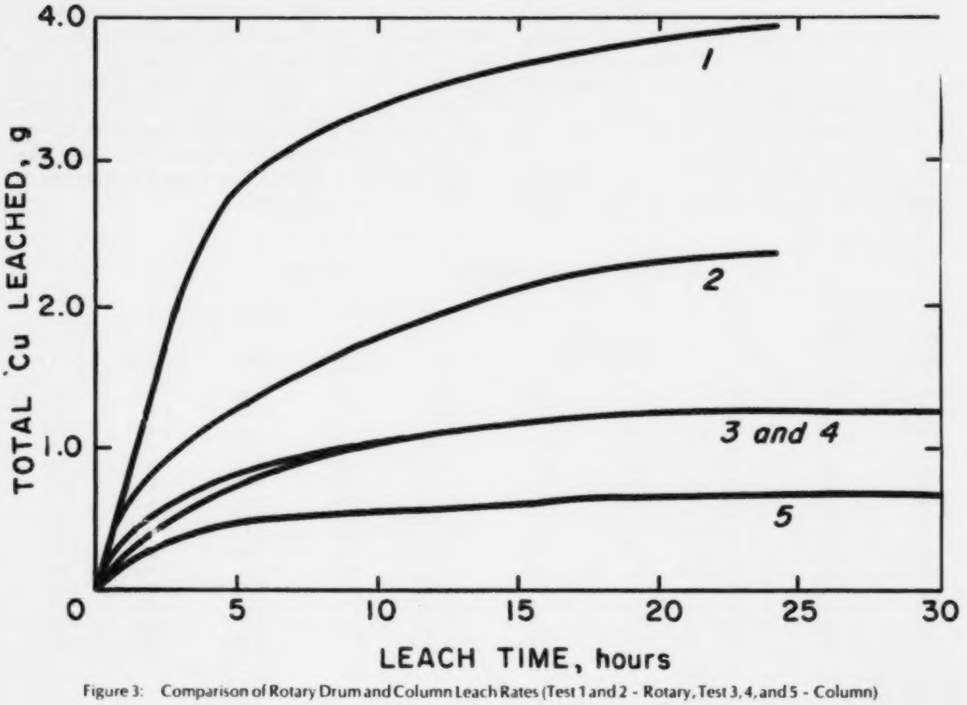

Figure 3: Comparison of Rotary Drum and Column Leach Rates (Test 1 and 2 - Rotary, Test 3, 4, and 5 - Column)

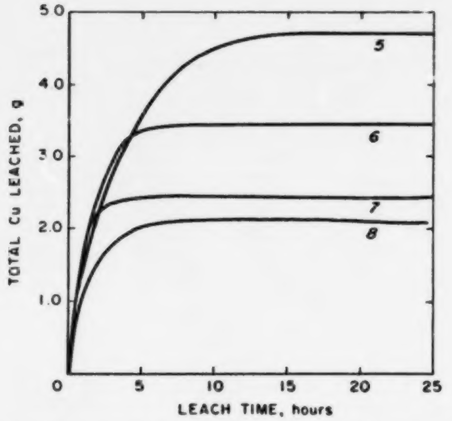

Figure 4: Rotary Leach of Ferrous Fraction from Incinerator B

(47 percent) was about as effective as 11 percent hydrochloric acid (Table 3). Extraction efficiencies were calculated from a material balance of tin in the solution and the smelted ingot. In 16 hours the residual tin level achieved in the product was found to be about 0.1 percent. Beyond this time, HCl was consumed and iron was dissolved with no further significant increase in tin removal. It was later learned that the solder inside the seam (which was mechanically masked from the leach solution) contained much of the residual tin. During the neutralization process for recycling the HCl,[6] tin and iron would be precipitated as oxides.

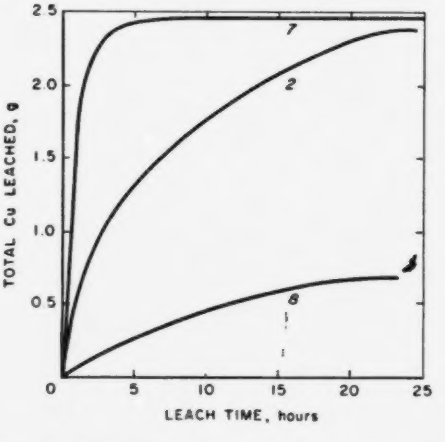

Figure 5: Comparison of Leach Rates from Several Incinerators in Rotary Drum

TABLE 3
Hydrochloric Acid Leach for Tin Removal, Incinerator B

	Pct	Pct Sn		
Time, hr	*Fe recovered*	*residual*	*calculated in charge*	*extracted*
7	89	0.11	0.30	67
7	82	0.12	0.23	58
16	77	0.10	0.30	74
22	57	0.09	0.17	77

The second system which holds promise is the roasting of the iron at 825°C after it has been coated with a mixture of $CaCl_2$ and powdered coke. The chemical reactions involved are:[7]

$$SnO_2 + C - SnO + CO \qquad (2)$$

$$SnO + CaCl_2 - SnCl_2 + CaO \qquad (3)$$

The iron probably formed $FeCl_3$ which was evolved together with $SnCl_2$. The results are given in Table 4.

The tin calculated to be in the charge was determined from the total tin in the ingot and the wash solutions. They were compared to an average tin content of the charge as determined from previous data in which no volatiles were formed. The comparatively low values gave indirect evidence that the tin was volatilized during the roasting. In general, 2 to 4 hours were needed to reduce the tin to 0.1 percent or less. Increased roasting time led to lower residual tin and lower iron recovery. In a commercial operation, these chlorides could be recovered and separated.

The investigation of surface fusion is continuing with this system and other chloride reagents. The simultaneous removal of iron and tin is probably necessary to reduce the tin to an acceptable level. If this technique has economic merit, then methods for the recovery and separation of the tin and iron will be developed.

CONCLUSION

The ferrous fraction from incinerator residue contains residual copper and tin which exceed the levels for electric furnace feed scrap. On a laboratory scale, the technology is being developed to produce a quality scrap product. Work at the Bureau of Mines has demonstrated that ammonia leaching removes the copper, and either hydrochloric acid leaching or roasting with a chloride-coke mixture reduces the tin level. In these processes, copper and tin can be recovered as byproducts with available technology. Incinerator residue then should be considered as a potentially valuable source of iron, copper, and tin.

TABLE 4
Tin Removal by Reaction of Tin-Iron Diffusion Layer with a Chloride-Carbon Mixture

Charge, g	Flux		Wt. pct coating	Roast time, hr	Pct Sn			Pct Fe recovered
	$CaCl_2$, g	C, g			residual	calculated in charge	average charge	
710	88	8	14	1	0.10	0.10	0.25	85
729	131	12	20	1	0.12	0.13	0.25	85
729	140	13	21	2	0.11	0.11	0.25	83
729	118	11	18	4	0.07	0.06	0.25	74
850[1]	174	19	50	1	0.13	0.17	0.25	83
850[1]	174	19	50	2	0.10	0.13	0.25	78
850[1]	174	19	50	4	0.07	0.10	0.25	63
1000	124	12	14	2	0.11	0.13	0.18	81
1000	127	13	14	4	0.09	0.09	0.18	71
1000	164	16	18	Induction	0.10	0.10	0.18	99

[1] SiO_2 added

REFERENCES

1. Kenahan, C. B., P. M. Sullivan, J. A. Ruppert, and E. F. Spano. "Composition and Characteristics of Municipal Incinerator Residues." Bureau of Mines Report of Inv. 7204, 1968, 20 pp.

2. Stanczyk, M. H. and P. A. Bloom. "Copper Recovery from Segregation Flotation Concentrates by Ammoniacal-Ammonium Carbonate Leaching," Bureau of Mines Report of Inv. 5826, 1961, 6 pp.

3. Benedict, C. H. "Ammonia Leaching of Calumet Tailings," *Eng. & Min. Journal*, *104*, 43 (1917).

4. Halpern, J. "Kinetics of the Dissolution of Copper in Aqueous Ammonia," *J. Electrochem. Soc.*, *100*, 421 (1953).

5. Lu, C. Y. B. and W. F. Graydon. "Rates of Copper Dissolution in Aqueous Ammonium Hydroxide Solutions," *J. Amer. Chem. Soc.*, *77*, 6136 (1955).

6. "Pickling Acid Recovery May Pay for Itself," Steel, Nov. 18, 1968, p. 69.

7. Collins, D. N. and D. V. Jackson. "Improved Recovery of Tin from Ores," Warren Spring Laboratory, Stevenage, Herts, England, Oct. 1966, 29 pp.

Research on Processing Systems and Utilization of Automotive Materials

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Bureau of Mines' studies indicate that two methods offer promise for reducing the accumulations of junked automobiles scattered across the country. For urban centers that discard at least 40,000 cars per year, the preferred method is shredding. In this procedure, huge hammer mills shred automobiles stripped of radiator, battery, motor, and seats into fist-size chunks which are passed over a magnetic separator to separate clean steel from nonmagnetic materials. For areas that do not discard enough cars to support a shredder plant, a combination of incineration, hand-tool dismantling, and baling can be profitably used.

The principal research effort at the Salt Lake City Metallurgy Research Center has been directed to determining the economic and technical practicality of the incineration, hand-dismantling process. Time and motion dismantling studies were made on selected cars, and all products were chemically analyzed. Information thus derived was used in making a cost evaluation as to the economic feasibility of the method. When the cost evaluation indicated the profitability of the method, a smokeless incinerator was constructed and successfully tested.

In addition to the major effort, some work has been done on the problem of recovering the nonferrous metallic values in the nonmagnetic rejects from automobile shredding operations. Research thus far has been directed to the separation of the metallic portion of the product from the glass, dirt, rubber, and other nonmetallic portions. Future studies will emphasize the recovery of the different metals in the metallic concentrate as marketable products.

Cost Evaluation of Incineration, Hand-Dismantling, Baling Procedure

The incineration, hand-dismantling, baling method encompasses the following sequential procedure:

(1) Remove and separate wheels, tires, battery, and radiator and puncture gas tank, oil pan, and drive shaft; also break out glass.

(2) Burn combustibles in a smokeless incinerator; and after cooling, cut engine and transmission from bulk.

(3) Remove starter and generator from engine and disassemble or leach. Separate all cast iron, steel, and nonferrous components in engine.

(4) Strip all nonferrous trim, grills, body wiring, handles, electric motors, etc., from hull; and bale clean steel.

The steel produced from such an operation contains less than 0.1 percent copper and is acceptable to all steel manufacturers.

A cost evaluation was made of this method for handling 48 junked cars per day. All data were based on dismantling a typical automobile composited from a study of 15 vehicles representative of the largest selling car models during a 10-year period. The typical car was estimated to contain $55.94 in recoverable metallic values as presented in Table 1.

The cost of recovering the $55.94 was estimated to be $51.24 based on capital and operating costs as given in Tables 2 and 3.

An annual rate of return of 19.0 percent (calculated on a discounted cash flow basis) was obtained for a smokeless incinerator operation coupled with hand-tool dismantling procedures.

Developing A Smokeless Incinerator

As incineration is a must prior to baling, and is desirable prior to shredding, a study was initiated in the problem of designing, building, and operating a flexible smokeless incinerator of moderate capacity.

The smokeless incinerator described in this paper was designed, built, and operated by the U.S. Bureau of Mines in cooperation with the Wasatch Metal and Salvage Company of Salt Lake City, Utah. Construction of the incinerator was completed in October, 1969, and preliminary

TABLE 1
Recoverable Metallic Values in Composite Automobile

Metal	*Pounds*	*Price*		*Value*
No. 2 bundle iron	2,614	$18.80	per ton	$24.44
Case iron	429.3	42.20	per ton	9.06
Copper: Radiator stock	15.4	.3275	per lb.	5.04
No. 2 heavy and wire	13.8	.396	per lb.	5.46
Yellow brass solids	2.7	.31	per lb.	.84
Zinc, die castings	54.2	.0625	per lb.	3.39
Aluminum, cast, etc.	50.6	.124	per lb.	6.27
Lead: Battery	20.0	1.40	per battery	1.40
Battery cable clamps	.4	.11	per lb.	.04
Total	3,200.4			$55.94

TABLE 2
Estimated Capital Costs for Scrap Yard

Fixed capital:	
Direct cost:	
Baler	$ 72,000
Alligator shear	13,200
Dismantling conveyor	8,400
Jib boom and hoist	1,900
Truck scale	3,500
Miscellaneous tools and equipment	8,100
Office building	7,300
Storage and shop	13,000
Dismantling building	5,000
Fencing	3,700
Utilities and miscellaneous facilities	6,000
Crane (with electromagnet)	15,000
Crane	11,500
Boom truck	6,500
Pickup truck	3,000
Incinerator	22,000
Subtotal	200,100
Land (5 acres with railroad siding)	50,000
Subtotal	250,100
Indirect cost and contingency, 10 percent	25,000
Total	$275,100
Working capital:	
1 week's supply of raw material (131,000/52)	$ 2,500
40 days' product inventory (40/365 × 614,900)	67,400
Total	$ 69,900
Total investment:	
Fixed capital	$275,100
Working capital	69,900
Total	$345,000

TABLE 3
Estimated Annual Operating Costs for Scrap Yard

Direct cost:	
Materials and utilities:	
Automobiles (48 x 250 x $9 per car)	$108,000
Fuel ($520 per month x 12)	6,200
$O_2 + C_2H_2$ ($1,400 per month x 12)	16,800
Electricity (436,000 kwhr per year x 0.015 per kwhr)	6,500
Subtotal	$137,500
Direct labor:	
Labor (42 at $3 per man-hour)	$262,000
Supervision (7½ percent)	19,700
Subtotal	$281,700
Maintenance:	
Labor (2 percent x $275,100)	$ 5,500
Supervision (20 percent)	1,100
Materials	5,500
Subtotal	12,100
Payroll overhead (20 percent x $288,300)	57,700
Operating supplies (20 percent x $12,100)	2,400
Total	$491,400
Indirect cost: Administration and overhead (15 percent x $296,200)	$ 44,400
Fixed cost:	
Taxes and insurance (2 percent x $275,100)	$ 5,500
Depreciation (10 years)	22,000
Annual operating cost, exclusive of incineration	563,300
Incinerator operation (48 x 250 x $4.30)*	51,600
Total annual operating cost	$614,900

*Published cost of $3.75 per car in 1961 updated to 1968.

testing was then completed to examine and generally define suitable operating conditions, capacity, and costs. The exact costs for construction of the incinerator are not yet available. The incinerator was built of both new and used materials which affected both the design and cost. About $22,000 was spent on materials and construction. The capital cost of a similar incinerator built entirely of new materials in another area probably would be higher.

Design and Operation

Several different types of incinerators have been built and operated by the auto scrapping industry during the past 10 years. These have ranged from small pit-type incinerators capable of burning 10 to 15 cars a day to large, conveyorized, kiln-type burning chambers which can burn in excess of 300 cars per day. Car bodies were burned in different positions and conditions using a range of supplementary air, gas, and oil burners. Air pollution control devices tested included oil and gas afterburners, electronic precipitators, and water-scrubbing chambers. Materials and types of construction included steel- or concrete-lined earthen pits, all-steel chambers, and garage-type chambers with steel framework and refractory lining. Many of these incinerators failed or were discarded because of poor design, inadequate materials of construction, or high operating costs.

The available information on automobile incinerators indicated that a refractory-lined, garage-type incinerator with a natural gas afterburner and designed for quick loading, burning, and discharge of two cars at a time would meet the requirement of simplicity, relatively low capital and operating costs, and effective smokeless burning of properly prepared cars.

A design capacity of six cars per hour was selected. This size incinerator would be capable of burning the 12,500 cars per year that are discarded by a population group of approximately 300,000 people. Areas with such population groups have the greatest need for an automobile incinerator, as the accumulation of abandoned cars is significant, yet the volume of cars discarded each year is insufficient for a shredder-type plant.

The garage-type incinerator consists of three principal components: (1) a primary burning chamber in which the combustibles are ignited and burned, (2) an afterburner chamber in which the smoke is further heated and consumed, and (3) a stack which creates a controlled draft for drawing in air from below the burning cars in the primary chamber and withdrawing the gaseous products for discharge.

Design

The primary burning chamber is 22 feet long, 14 feet wide, and 9 feet 5 inches high. The chamber has concrete block outer walls protected by a structural steel framework, single-course refractory brick inner walls, a suspended refractory brick ceiling, and a concrete floor with railroad tracks on which the loading cart rides. Castable-refractory-lined hinged doors are at either end of the chamber. The gable roof is covered with galvanized steel. A small port is in the outer wall opposite the afterburner chamber. A castable-refractory-lined damper door covers the ceiling-high flameport opening to the afterburner chamber. The damper is controlled in open or closed vertical positions by a crank and a counterweighted pulley.

The double-course refractory-brick-lined afterburner chamber is 9 feet 4½ inches long, 3 feet 9 inches wide, and 8 feet 3 inches high and has an outer concrete block shell. The afterburner chamber is situated between the primary burning chamber and the stack. A free-standing brick checkerwork — 36 inches deep, 45 inches wide, and 99 inches high — fills the space between the flameport opening and the breech (the short connection between the outlet of the afterburner and inlet of the stack). The checkerwork serves as a heat sink to assist the 6.5 million BTU per hour gas burner in consuming the smoke particles. The burner has five heads and is capable of producing a 1,350°F temperature in the afterburner chamber within 1 hour after starting at ambient temperture.

The tapered steel stack is 54 feet high and is partly brick-lined. The lower 32-foot steel section of the stack is 5 feet 8 inches in inner diameter and is lined with a single course of refractory brick to produce a 4-foot 9-inch inner diameter. The upper unlined 22-foot steel section is 4 feet 9 inches in inner diameter.

Operation

Two cars—minus the battery, radiator, wheels, and tires; with the gas tank, oil pan, and sealed shafts punctured; with the glass broken out; and with the trunk lid sprung open — are loaded onto a four-wheel steel cart. The cars are turned on their sides and placed top to top. (Alternatively, the frame, engine, and running gear may be removed and three cars loaded onto the cart.) A small quantity of liquid fuel is splashed onto the cars' upholsteries as the cart is pulled into the burning chamber and the previously burned charge is removed. The cars are ignited, and the smoke is drawn through the damper door opening into the afterburner chamber. The sliding port opening, air blower, and door flaps are adjusted to obtain the best burn.

Results of Preliminary Test Runs

After completion, the incinerator was tested intermittently for approximately 3 months. These test runs were made to determine if the incinerator required modification in design and if it could achieve the required burning capacities with relatively smoke-free burning. Fuel and labor requirements were defined to enable estimating probable operating costs. Some minor modifications of the original construction features were made — principally in the arrangement of the brick checkerwork and the afterburner heads; but the basic structure proved satisfactory as designed.

Based on preliminary tests, the incinerator is capable of burning an average of four cars per hour when the cars are burned with the engine, transmission, frame, and running gear still attached. When the engine and transmission have been removed, the incinerator averages about five cars per hour; if the frame and running gear also have been removed to permit loading three cars at a time, the incinerator will burn an average of 7.5 cars per hour. Optimum operating conditions have not been determined and several operations have not been automated, so the throughput of the incinerator probably can be improved.

In a recent continuous operation in which 26 cars were burned, the total incineration time was 378 minutes. The smoke emerging from the stack was observed during this entire period and compared with a Ringelmann chart as to density. These observations indicated that the stack effluent ranged between a No. 1 and No. 3 Ringelmann for a total of 11 minutes. This means that the incinerator produced a stack effluent of No. 1 Ringelmann or less for over 97 percent of the burning period. Other better controlled, continuous incineration periods have produced slightly better results, indicating that the incinerator should meet or exceed most air cleanliness standards.

From the operating data derived from the initial test runs, the operating cost of the incinerator was estimated as $2.75 per car, plus or minus 20 percent. This cost estimate is based on 90 percent operating time to burn an average of 215 cars per 40-hour week (11,[illegible]0 cars per year) in an incinerator that costs $22,000 and is depreciated in 10 years. Direct operating costs are $2.25 per car including $0.80 for gas, electricity, and kerosine; $1.10 for direct labor comprising two men paid at a rate of $3.00 per hour; and $0.35 for maintenance and operating supplies. Indirect operating costs — based on factors for administration, overhead, taxes, insurance, and depreciation at 10 percent interest — are estimated at $0.50 per car.

Potential for Increased Utilitization of High-Quality Automobile Scrap

The markets for automotive scrap have been mixed. Foundries provide a ready market for clean automotive cast iron. Custom smelters, foundries, chemical plants, and miscellaneous manufacturers also provide outlets for the nonferrous metals from automotive sources if properly segregated and cleaned. Battery plates may be sold to lead smelters; aluminum pistons and grills to secondary aluminum smelters; and radiators, copper wire, and other copper-containing parts to several different outlets. However, the market for No. 2 bundle steel has been somewhat limited.

Use of scrap steel has declined in the past 10 years as basic oxygen furnaces, which use lesser amounts of scrap, have gradually supplanted many open-hearth furnaces. Use of auto scrap has declined to an even greater degree because of the inferior quality of auto scrap containing objectionable amounts of copper, zinc, and aluminum. As the incineration, hand-dismantling procedure postulated in this report produces high-quality steel scrap low in nonferrous metal, such scrap should become more readily marketable.

Production of clean No. 2 bundle steel scrap containing minimal quantities of copper, zinc, and aluminum should permit the use of such scrap not only in electric, basic oxygen, and open-hearth furnaces, but also in blast furnaces. Iron ore pellets containing 60 to 65 percent Fe are nominally quoted at 26.0 cents per iron long ton unit, which is equivalent to 1.162 cents per pound of iron. Baled scrap containing 95 percent iron, at $18.70 per ton, is equivalent to a price of 0.991 cent per pound of iron. Thus, if clean No. 2 bundles can be cut into sizes suitable for blast furnace feeding (approximately 6 inches square) at reasonable cost, the No. 2 bundle scrap cubes should be more than competitive with pellets as a blast furnace feed. In addition to being as reasonable in cost as pellets, scrap of this quality should have the advantage of markedly reducing the usual quantity of 1 ton of coke and ½ ton of limestone required per 1.5 tons of iron ore pellets used in the blast furnace.

When low-quality No. 2 bundles constitute part of the feed to open-hearth and basic oxygen furnaces, the appreciable quantities of iron oxide dust and fume produced are contaminated with nonferrous impurities. As these impurities prevent the recycle of the dusts, a major disposal problem is created. Use of high-quality No. 2 bundles as feed material should obviate this problem and permit recycling of the furnace dusts and fumes.

Recovery of Metals from Shredder Nonmagnetic Rejects

Currently, automobile shredding plants located in the major cities of the United States process about 5 million cars per year. As the nonmagnetic reject averages about 400 pounds per car, more than 1 million tons of shredder plant reject is discarded annually, chiefly to municipal dumps. The nonmagnetic rejects are a complex mixture of metals and nonmetals. The principal non-metallic constituents are glass, rubber, plastics, cloth, paper, dirt, and rust. Iron, aluminum, copper, zinc, and lead in different forms comprise 25 to 35 percent of reject product.

An investigation is underway to assess shredder rejects as a potential source of additional income by developing methods for separating and recovering the nonferrous metals as marketable products. The work completed to date comprises evaluating alternative means for separating the metals from the nonmetallics contained in three samples of reject products obtained from three shredder plants. The metallic and combustible content of the three samples is given in Table 4.

TABLE 4
Analysis of Shredder Nonmagnetic Reject Samples

	Weight, pounds per ton		
Component	*Sample A*	*Sample B*	*Sample C*
Cu	42	84	52
Zn	140	296	224
Al	34	28	20
Pb	26	32	19
Fe	316	138	356
Ni	3	5	3
Cr	1	2	1
Loss on Ignition	454	576	280**
Other*	984	839	1,045

*Chiefly glass, insulation, and dirt.

**Part of feed to shredder was incinerated cars.

As indicated by the analyses listed, shredder rejects are notably variable in composition. This variability is partly attributable to the fact that the car hulks fed to any shredder include many types that are partly or completely stripped, dismantled, and incinerated. The type of hammermill used and the effectiveness of the magnetic separators are other factors that affect the quality and nature of the nonmagnetic reject.

Air elutriation of screen-sized fractions of dry nonmagnetic rejects has proven the simplest and most effective method for separating and concentrating the metallics in the rejects. The air elutriation method evolved from laboratory testing comprises screening the rejects on 1-inch and ⅜-inch screens and rejecting the minus ⅜-inch material, which consists chiefly of glass and dirt. The two coarse fractions are then fed into a vibratory feeder which discharges onto a moving belt conveyor. The belt conveyor drops the material into a right-angle horizontal air stream produced by a centrifugal blower of 1,200-cubic foot per minute capacity with an 8-inch square outlet set below the belt pulley discharge. The rejects are blown into a 12-inch wide by 6-foot long compartmented chamber, open at the bottom and front end.

The metals, plastics, hard rubber, and other materials of high density fall into the first compartments; and the paper, textiles, fibers, and lighter material are rejected into the compartments distant from the blower. Air elutriation of the plus ⅜-inch reject materials from all three samples recovers an average of 97 percent of the metallic content in a product containing 84 percent metal. About 95 percent of the nonmetallic materials are rejected.

Testing is continuing to improve the conveyor-blower separation method and to comparatively evaluate this method with a tube-type air elutriation system. Hydrometallurgical, pyrometallurgical, and such beneficial procedures as additional air elutriation, magnetic separation, hand sorting, and sink-float also are under investigation for separating the individual metallic components from the air-elutriated primary concentrates.

REFERENCES

1. Dean, Karl C. and Joseph W. Sterner. "Dismantling a Typical Junk Automobile to Produce Quality Scrap," Bureau of Mines Report of Inv. 7350, December 1969, 17 pp.

2. Ellsworth, Richard D., Edward P. Ballinger, and Richard B. Engdahl. *Final Report on Preliminary Survey on Development of an Incinerator for Removal of Combustibles From Scrapped Automobile Bodies to Institute of Scrap Iron and Steel, Inc.*, Battelle Memorial Inst., August 30, 1957, 21 pp.

3. Bureau of Mines. *Ringelmann Smoke Chart (Revision of IC 7718)*, Int. Circ. 8333, 1967, 4 pp.

4. Chindgren, C. J., K. C. Dean, and J. W. Sterner. *Construction and Initial Testing of an Automobile Incinerator*, Bureau of Mines Tech. Prog. Report 21, 1970, 8 pp.

5. Kaiser, E. R. and J. Tolciss. *Smokeless Burning of Automobile Bodies*, New York Univ. College of Engineering, Tech. Rept. 764-2, June 1961, 31 pp.

The Role of the Engineer in Environmental Improvement and Resources Recovery

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In examining the role of the engineer, it is necessary to think of engineering in its generic sense. It is necessary to think in terms of all the various engineering disciplines.

For the most part, the engineer is the practitioner, the implementor; he is the individual who uses available technology to design a system, process, or physical product. Probably more than any other group, engineers have been responsible for the many processes, materials, devices, machines, structures, systems, and other physical facilities that make the material standard of living in the United States the highest in the world and the highest of all time. Although the engineer can applaud his achievements in making possible this high standard of living, he must accept a major portion of the blame for the concurrent deterioration in the quality of the environment.

It does not take an in-depth investigation to determine that there is no segment of the engineering profession that is not responsible for some design that contributes to the degradation of the quality of the environment. If this is so, we must ask the basic question: why is that profession which is primarily responsible for the good way of life, which most of us in this country enjoy, the same profession that is primarily responsible for the degradation in the quality of our environment?

Although this paper will not provide a profound answer to this important question, nor one that is not already known, it will examine some of the factors that may be fundamental to the enigma in which we, as engineers, find ourselves. We are literally on the spot, and it is only by trying to develop an understanding of fundamental cause and effect relationships that we can hope to establish proper approaches to the solution of our environmental problems.

Let's look at some of the factors that might have contributed to present-day conditions:

1. Lack of concern, on the part of engineers, of the consequences of actions,
2. Ignorance of the problems being created by their actions,
3. Lack of essential technology to prevent adverse impact on the environment,
4. Lack of definitive design standards for environmental quality control, and
5. Economic constraints.

This paper will summarily pass off any consideration of the premise that engineers as a group are unconcerned about the consequences of their actions. The vast majority of engineers are conscientious, serious-minded individuals concerned about doing a worthwhile job. These individuals would be vitally concerned about the consequences of their actions. However, the position of the engineer may influence his objectivity. While we speak freely of the engineering profession, there are relatively few engineers registered as professional engineers. The vast majority of engineers work as part of an organization. They do not work directly for the ultimate consumer of the product of their services. They are not required by law to become registered as professional engineers and, consequently, may never develop the higher sense of professionalism that often seems to go along with being registered. In the event that the best interests of an engineer's employer are not in harmony with those of the general public, he is confronted with an inherent conflict of interest. A higher sense of responsibility and loyalty to his employer than to the general public is likely to influence his actions.

As you know, the engineering profession is highly segmented and specialized. More often than not, the effort of the individual engineer is restricted to a limited portion of the total project. As a member of a project team, he may have little authority, responsibility, or even knowledge of the potential impact of his project or his product on the environment. If the engineer graduated prior to the past two to five years, it is most likely that he received no undergraduate training on subjects of environmental pollution control unless he was enrolled in the civil engineering curricula. Even today, major engineering schools may provide no training on the possible impact of engineering designs on environmental quality. As environmental engineers, we are appalled at the apparent ignorance of members of other engineering disciplines relative to the adverse effect of their designs on the environment.

So, it is possible that lack of knowledge of all aspects of a project or product or inadequate technical training on the impact of engineering designs on environmental quality could contribute to inadequate engineering design for environmental protection.

Although adequate technology may not yet be available to provide low cost, technically feasible solutions to *all* of the environmental quality control problems, most professionals in the field will agree that currently available technology, if used, would significantly reduce most of our environmental quality control problems. It is not so much the lack of environmental quality control technology as the lack of adequate environmental quality criteria that influences environmental quality.

There is ample evidence that engineers can design to meet most any criteria so long as the design requirement can be expressed in quantitative terms. It has only been in the past few years that specific quantitative requirements have been available in the field of environmental quality control. Those design requirements that have been available have been almost devoid of specifications on reliability. While reliability of performance is of paramount importance to the space and aeronautics fields, it has been given little attention in the environmental control field. This is possibly because of the relative significance of failure. Failure and crash of a 747 airliner would be catastrophic. Failure of a single automotive exhaust control device or a small water pollution control system would be relatively insignificant. On the other hand, failure of some industrial operation or the failure of an industrial or municipal wastewater control system has killed thousands of fish and birds and even endangered the lives of many people. Recent major oil pollution incidents have been due to designs of low reliability. Thus, the reliability of control of treatment systems should be related to the impact of failure on the ecology of the environment.

In the past, considerable leniency and understanding have been demonstrated by regulatory agencies relative to so-called "accidents" or "emergencies." Some of our regulatory people have been so pleased to have any treatment at all that they did not concern themselves with reliability. Punitive actions have been taken against unreliable or inadequate designs. Sometimes the regulatory people have been helpless to take punitive action because they were a party to the problem. Their design standards were directed toward the detailed manner in which the result should be attained rather than toward the performance criteria that must be met. Therefore, they could not complain when the results obtained, using their recommendations, were inadequate. Irrespective of past performance, if engineers are provided with specific qualitative standards on design performance that will be duly enforced, they will design to meet the required standards.

Economic constraints, most assuredly, have been a prime cause for designs that have had an adverse effect on the quality of the environment. Many engineers design products or facilities that must be economically competitive. They must meet basic use or service requirements at "least cost." In evaluating "least cost solutions," the engineer uses those economic parameters that are available to him and those regulatory constraints adaptable to his situation. Many of us in the environmental engineering field have been most frustrated because we have been unable to justify needed pollution control facilities on the basis of conventional economics. In the case of new facilities, a ninety percent reduction in pollution can be obtained by a three to fifteen percent increase in costs, depending upon whether we are dealing with a power plant, an oil refinery, a pulp and paper mill, or an automobile.

We have been frustrated because the need for pollution control has been obvious and we have been sure that our inability to provide economic justification was due to the lack of proper parameters — not due to the lack of true economic incentives. However, if proper parameters are not available for use in economic evaluations, it should be obvious to all that conventional economic considerations will control decisions. Practical experience to date would certainly indicate that conventional economics are not adequate to insure proper control of the quality of the environment. Although adequate control of the quality of the environment may be attainable by regulatory constraints, the fact that we are an economic-oriented society makes it highly desirable to use economic parameters in justifying needed environmental quality control designs.

It should be axiomatic that each and every service or product should be provided at least total cost to society. That is, the sum of the market price plus costs associated with use and disposal should be minimal. This concept has been recognized and has influenced the actions of some industries for over 30 years. The hard facts of economic reality have caused modifications of the basic "least cost" concept by what industry has called "enlightened self-interest."

The "least cost" concept is theoretical, idealistic, and impractical in pollution control practice because least cost to society probably can be attained only by increasing costs on one segment of society to reduce costs for another segment. For example, if we assume that there are real and definable costs associated with adverse pollution and that those costs are higher than the control costs, the manufacturer who strives for least overall cost for society would be economically penalized because his costs would be higher than those of his competitor who discharged his wastes at no costs to himself.

Today, it pays to pollute. At least it pays to transfer costs to the "other fellow." We appear to reward the inefficient and recalcitrant and penalize the efficient and compliant. Although my remarks have referred to the manufacturer of a product, the concepts apply equally to organizations providing a public service (e. g., a municipality).

In addition, the practical aspects of enforcement under our present system make it necessary to require one polluter to correct his problem prior to that of another. Consequently, the polluter who has corrected his problem is at a competitive disadvantage compared to the one that is given more time. This naturally encourages resistance on the part of the polluter who must incur costs first. Such a system is not equitable. The weaknesses of our present system encourage precisely what is happening: adverse degradation of the environment.

Our current system of moral persuasion, fines, and injunctions has been disappointing it its effectiveness. Enforcement agency budgetary problems have made it necessary to rely heavily on the honor system. Our approach appears to be either insufficiently punitive or overly punitive. It makes pollution control a moral issue. Enforcement can become subjective rather than objective. We are confronted with questions such as, how clean is clean? how much dirt is acceptable? or we are asked to choose between unrelated things such as good schools or clean streams; good housing or clean air; jobs or a few fish. We all know that there must be proper priorities; we cannot do everything at once. However, it is obvious that the country is badly in need of a different approach for achieving needed control. Dr. A. J. Teller has stated, "To effectively solve our problem we must view the total system and bind morality to technology via economics."

How much better it would be if it were cheaper to *abate* rather than *create* pollution. Surely a better and more equitable system can be devised, and there is no segment of our society that is more knowledgeable or better qualified to undertake the assignment of devising such a system than the engineering profession.

To date, one of the most commonly suggested new ways of achieving desired environmental quality is by the use of taxation or tax relief. The appropriate use of taxation could assist in providing a more conventional economic approach for enhancing the quality of the environment. For example, the imposition of punitive, use, and resource loss taxes or the removal of existing tax incentives would *increase* costs for those polluters who are not providing adequate control facilities. Conversely, tax relief incentives for the installation of proper pollution control facilities would *reduce* the costs of attaining desired environmental quality. It is not specifically being recommended that taxation be adopted as the means of modifying the economics of pollution control. However, taxation is currently being used to modify incentives in other parts of our economy; therefore, this approach should be considered as an alternative.

One of the prime deterrents to waste recovery and reuse, in fact, is that recovery and reuse are more expensive than the use of raw materials. There is some evidence that tax incentives may contribute to this situation. As a specific example, the statement made by Senator Thomas F. Eagleton at the Senate Air and Water Pollution Sub-Committee in suggesting an amendment to Senator Boggs' proposal for a National Commission on Material Policy referred to mineral and sulfur depletion allowances and paper industry special capital gains advantages as deterrents to recovery and reuse.

In examining the role of the engineer in environmental improvement, it is necessary to conclude that the engineer has made a considerable contribution to the present-day deterioration of the quality of the environment. As he may be a prime contributor to the deterioration of the environment, so he can do more about the improvement of the environment than any other segment of society. His technical contribution is not enough. He must provide moral and policy leadership for the common good. He must provide personal leadership by example and organizational leadership through objectivity, forthrightness, integrity, and dedication to purpose.

Theoretically, engineers are the single most powerful group in the United States in relation to improving environmental quality. The major problem encountered is most likely to be in obtaining a unified effort by all engineers because there is no single organization which is truly representative of *all* engineers. However, we can — all of us — work through the various societies, each of which has different goals and purposes.

Therefore the following "Plan of Action" is suggested:

1. First, that the National Academy of Engineers be empowered, as the overall coordinating body, to initiate a study of the role of the engineering profession in the control of the quality of the *total environment*. It should coordinate the efforts of specific engineering disciplines. It should analyze and evaluate the role of each of these disciplines in environmental quality control. It should critically analyze our present-day policies and methods for controlling the quality of the environment. It should evaluate alternative methods of providing incentives for abating, rather than creating, pollution.

2. In order to make this work possible, it should be recommended to Congress that the National Academy of Engineers be given a special grant at the earliest possible date. The grant perhaps could be a part of one of the current environmental bills now under consideration. The study to be completed under the grant should be coordinated with any work done by the recently established White House National Council on Environment.

3. The Engineers Joint Council should be revitalized and strengthened because it represents the largest group of affiliated societies. The Engineers Joint Council could assist the National Academy of Engineers by developing a study which would establish the role of each of its constituent groups in creating pollution problems. The individual societies should look at what their designs are doing to the environment and why. This would be one method of establishing research needs and priorities in the area of control and in determining a new approach to the evaluation of economic incentives for pollution control.

4. The National Council of Engineering Examiners should examine the studies of the various engineering societies and should strongly recommend registration in all engineering disciplines that influence the environment and, by legislation if necessary, make registration a requirement. In addition, environmental problems should be considered in the preparation of all standard registration examinations to be sure that all registered professional engineers are aware that environmental control problems exist in their discipline. If registration changes the sense of responsibility for only a few engineers, it will be worth the trouble and cost.

5. Education, of course, is the major province of the American Society for Engineering Education, as well as of the American Academy of Environmental Engineers and the Founder Societies. As mentioned before, many major engineering schools have no courses in environmental control. Certainly, most of the major engineering disciplines pay very little attention to the impact of their designs on the environment. The possible exception might be the Civil Engineers who are beginning to think in terms of the total environment. There are excellent curricula in some schools, but, to my knowledge, there are only a very few which cover all aspects of the environment. In time, the general public should receive education as proposed in Senate Bills Nos. S.3151 or S.3237.

6. Above all, there must be the establishment of some governmental body, at a high level, which would set priorities and develop standards for all aspects of environmental quality control. The concept of a National Environmental

Laboratory, as proposed by Senators Muskie and Baker, (S.3410), in conjunction with an Environmental Quality Administration, as proposed by Senator Scott, (S.3388), deserves well-advised support by the engineering profession.

7. The engineering profession should support the efforts of the National Council on Environment, and request that it be empowered to establish quality parameters which may be open to future revision but will serve as design guidance for immediate use.

It must appear to the general public that modern technology has created a monster. Although the engineer has contributed to the creation of this hypothetical monster, he, the engineer, understands the monster sufficiently well so that he can develop the means for its control.

Let us hope that the engineering profession can bring some reasoned thinking into an area that has become an almost hysterical public issue. The country has reached almost universal agreement on the necessity for doing "something" about the quality of the environment. The quality of the environment cannot be improved by one discipline alone. As engineers, we will need the help of many professional disciplines, but, as the ultimate designers, we must provide the leadership. To do so, we must work as a coordinated generic group.

The environmental control cause is badly in need of unification of the engineering profession. The National Academy of Engineers has the potential of unifying the profession in this essential cause.

REFERENCE

1. Teller, A. J., P. E. "Should All Our Environmental Waste Be Economic Waste?" *Professional Engineer*, (Feb. 1970).

High Temperature Incineration

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INTRODUCTION

Urban solid wastes have been incinerated for the primary purpose of reducing their volume for subsequent disposal in landfills. Recovery and utilization of material and energy outputs have until recently been secondary and limited. This paper focuses on the potential for utilization of the material and energy outputs of incinerators derived by operation at higher than normal temperatures. High temperature incineration holds promise for conservation and economical recycling of inorganic mineral resources when compared to conventional incineration, dumping, or other disposal methods.

Solid waste incineration has been defined as the process whereby waste is reduced to an inert residue by burning at 1200°F or higher.[1] Three distinct outputs of material and energy are produced: an inert chiefly inorganic residue; both organic and inorganic gaseous and fine particulate emissions, including steam; and heat from waste combustion. While these same outputs are derived in high temperature incineration, the inorganic residue can be better separated and converted into high value products on being completely melted.

In conventional incineration practice, temperatures range from about 2500°F in the combustion zone to a minimum of 1500°F in the exit gas. Below 1500°F, smoke and odors may not be completely destroyed. If the exit gas temperature exceeds 1800°F, excessive slagging may occur on sidewalls and flues. Incineration processes are arbitrarily classified by temperature into the following:

(1) *Conventional or Low Temperature* — Where solid residue is primarily particulate and friable, including fly ash, and has not been heated above 1800°F.

(2) *Medium Temperature* — Where solid residue is bonded into large aggregates (clinkers) by partial melting (1800° to 2500°F).

(3) *High Temperature* — Where entire residue has been completely melted (2500° to 3200°F).

High temperature incineration produces a residue which can be classified into recoverable metallic and siliceous materials. Below about 2500°F, the melted metals and ceramics are intermixed. At higher temperatures, segregation of the molten fractions occur. The molten metal, by virtue of its immiscibility and density, tends to settle. This clean separation of the two phases, metallic and ceramic, on incineration at very high temperatures was achieved in studies conducted by IIT Research Institute, where City of Chicago raw garbage was used as the starting material.

High temperature incineration shows promise for solving problems commonly associated with conventional or medium temperature incineration. With high temperature incineration, combustion is more likely to be complete, creating less of a smoke hazard. Odors and dusts from combustion of organic and chemical wastes are more completely eliminated. Volume reduction (compaction) is increased due to densification by fusion and gas expulsion. The residue is a sterile, inert material and when used for landfill, poses minimal pollution potential to the ground, ground water, and environment. The process enables waste heat utilization, and glass and metal conversion into marketable products. The simultaneous recovery of all outputs offers an economically feasible process, whereas utilization of only one output could be difficult to justify.

Conventional Incineration

The rapid population expansion and higher standards of living have created a sizable increase in refuse from both homes and industry. Its disposal has plagued large cities with spiralling cost and disposal problems. These include the following:

(1) Air and water pollution from waste disposal dump sites.

(2) Unsightly odorous landfill areas containing rats and vermin.

(3) Shrinking and availability of landfill space within reasonable distance.

(4) Compounding of above problems due to expanding metropolitan areas, urban and suburban.

Of all the solid waste disposal methods, incineration offers the most significant volume reduction potential. According to data cited in a U.S. Bureau of Mines Report,[2] poor incineration reduces the volume of refuse by 75%, but efficient burning can reduce it by as much as 95%.

It was recently reported that 289 municipal incinerators were built, rebuilt, designed, or added to between 1945 and 1966.[3] Trends since 1945 have been toward larger incinerators of 1000 tons or more per day and from batch to continuous feed operations. Manually stoked furnaces have virtually disappeared. Auxiliary burners are only used during start up; after ignition, the heat from the burning refuse is sufficient to keep the incinerator operating. Where it has been the practice to introduce all the forced draft air under the grates to promote combustion, it is now customary to pass some over the fuel bed. After-burners are being employed to ensure more complete combustion of the organics. Increasing use is also being made of fans to augment natural drafts in the stack as well as air pollution control equipment. Cyclones, water sprays, spray or wet baffles, scrubbers, electrostatic precipitators, and baghouse filters are used with or replace previously used expansion chambers for pollution control.

Table 1 describes the characteristics of air pollution control equipment. Figure 1 presents a schematic cross-sectional diagram of a typical municipal incinerator. Incinerators are classified by three types.[4] Class 1 are those satisfying the following criteria: (1) constructed in or after 1950; (2) have two or more furnaces; (3) reduction is a minimum of 75% by either weight or volume; and (4) the facility has operating air pollution control equipment. Class 2 incinerators are identical except for the air pollution controls. Class 3 encompasses all other types.

Almost all modern conventional incinerators have multiple chamber designs that prevent pollution problems previously associated with single chamber types. These include the following: (1) the retort type in which the return flow of gases passes through a "U" arrangement of component chambers; (2) the in-line type in which the chambers follow one another in a line; and (3) the rotary kiln or tube type in which wastes traverse a single inclined tube with combustion gases flowing counter-current.

Incinerator temperatures must be closely controlled. Upper limits are usually dictated by the refractories employed, with special types being needed for temperatures in excess of 2400°F.[5] The four basic methods of controlling combustion temperatures are by excess air usage, radiant heat transfer, two-stage combustion, and direct heat transfer wherein water is added to the fuel to lower temperature.

High Temperature Incineration

To be classified as high temperature incineration, temperature levels must be high enough to melt all of the residue (generally, above 2800°F). Segregation of the melt into metal and ceramic depends on the time and temperature employed. Melting temperatures of refuse ingredients are presented in Table 2. While glass melts at temperatures as low as 1300°F, the viscosity of the resultant slag, because of solution with other oxides, sulfides, etc., remains high. Figure 2 is an example of complete separation, and Figure 3 is one of melting without separation.

Several systems involving high temperature incineration are currently being developed. Most include preliminary combustion similar to conventional incineration, followed by melting which separates the metal and siliceous slag. In systems without preliminary treatment, gravity feeding

TABLE 1
Types of Air Pollution Control Equipment

	Comparative Space (%)	*Efficiency (%)*	*Economic Factors*	*Performance Factors*
Electrostatic Precipitator	100	90-99	High installation cost. Low operating cost. Relative capital cost factor of 6.	Does not remove soluble gases. No installation working in U.S. municipal incinerators. Efficiency low on large particles.
Scrubber	33	90-99	Moderate installation and operating cost. High maintenance cost. Relative capital cost factor of 3.	Possible mist emitting from stack. Clarification and neutralization of wash water required. High water usage.
Mechanical Cyclone	33	75-90	Low initial and low operating cost. Relative capital cost factor of 1-1.5.	Low efficiency on small particles. Erosion from abrasive fly ash.
Baghouse Filter	110	99	High initial cost and costly bag replacement. Relative capital cost factor of 6.	Multitude of variables to be controlled coupled with the complexity of the effluent stream.
Settling Chamber	67	40-60	High installation cost. Low maintenance cost. Relative capital cost factor not applicable.	Low efficiency.

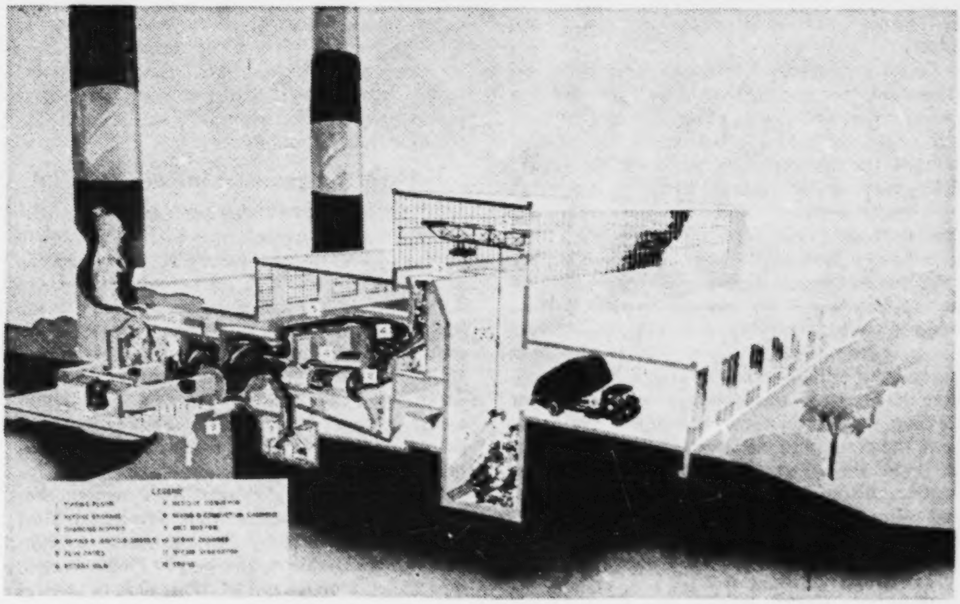

Figure 1: Section through South West Incinerator of City of Chicago

TABLE 2
Melting Temperature of Urban Refuse Components

Classification	*Materials*	*Melting Temperature °F*
Metals		
Tin		950-2000
Lead		620
Zinc		790
Magnesium		1200
Aluminum		1220
Iron		2800
Copper		2000
Ceramics		
White Ware	20% Al_2O_3	2800
Brick	65% SiO_2	
Stone	15% CaO	
Concrete		
Glass	12% Na_2O	2200-2400
	33% Al_2O_3	
	70% SiO_2	
	12% CaO	
Rust	FeO	2700
Ash		
Bones		2000-2200
Paper		

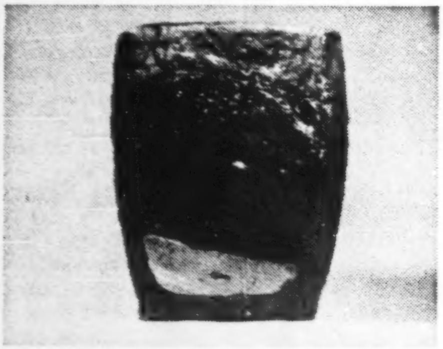

Figure 2: Melted Municipal Refuse Indicating Complete Metal-Ceramic Separation

introduces the refuse into the primary combustion chamber. The ignition burner may be either oil or gas fired and is normally used only during start-up until the heat released from the combustible waste material is sufficient to produce high enough temperatures. With high moisture content or low heat value in the waste material, burners can be re-ignited to maintain temperatures. Preheated primary and secondary combustion air is generally supplied to reach temperatures of 2800 to 3000°F, and care is required to protect the refractories from corrosion and wear. Water-cooled furnace walls are sometimes used for this purpose, and the water may be used to produce steam and power.

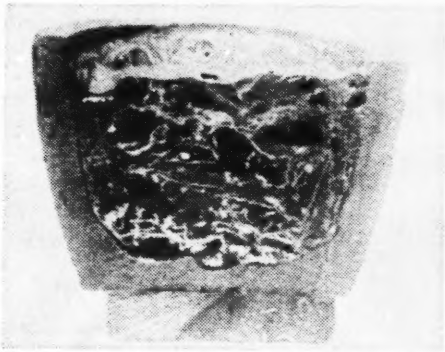

Figure 3: Melted Municipal Refuse Indicating Partial Metal-Ceramic Separation

While details have not been released on all high temperature incineration systems being proposed or developed, five systems have been analyzed.[6-10] Table 3 presents a classification according to functional characteristics.

Practically every type of furnace draft is represented in these systems. Feed methods range from direct charging to prior shredding of the refuse, to using a conventional grate incinerator as the primary combustion chamber. All use preheated air because of high moisture contents; some employ coke as a heat source and limestone for metal recovery. An observation based on this analysis is that the development of high temperature incinerators in the United States is still in an early stage, and designs are not close to being standardized. Only one high temperature incinerator is known to be in operation in Europe.[8] Except for the Hartford turbine (cyclone) furnace, all units are closely related in design to a typical cupola furnace shown in Figure 4. Various feed systems, fuel/hot air passages, and pollution control systems are added. In addition, most do not provide for ready recovery of the glass and metal in a form which would allow easy conversion into useful products, other than scrap metal or aggregates.

IITRI is developing techniques to form glass and metal products as part of the incinerator output. The molten glass can flow into a glass tank such as shown in Figure 5, and waste heat from the incinerator can be used for its heat. The glass can be refined, if required, and used in the molten condition to make products. In a similar manner,

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TABLE 3
Classification of High Temperature Incinerators

Function	*Type*	*Examples*
Heating System	1. Over draft	Melt-Zit Dravo
	2. Under draft	Torrax
	3. Side fired	Ferro-Tech
	4. Cyclone fired	Hartford
Feed Systems	1. Direct charge	Melt-Zit Torrax
	2. Shredder	Hartford Dravo
	3. Conventional incinerator grates	Ferro-Tech
Combustion System	1. Self combustion	Melt-Zit Ferro-Tech
	2. Coke combustion	Melt-Zit Ferro-Tech
	3. Auxiliary heating	Torrax (silicon carbide tubes)
Incinerator Output	1. Granulated product	Melt-Zit Dravo Torrax
	2. Molten separation	Ferro-Tech
	3. Pre-incineration separation	Hartford (magnetic sep.)

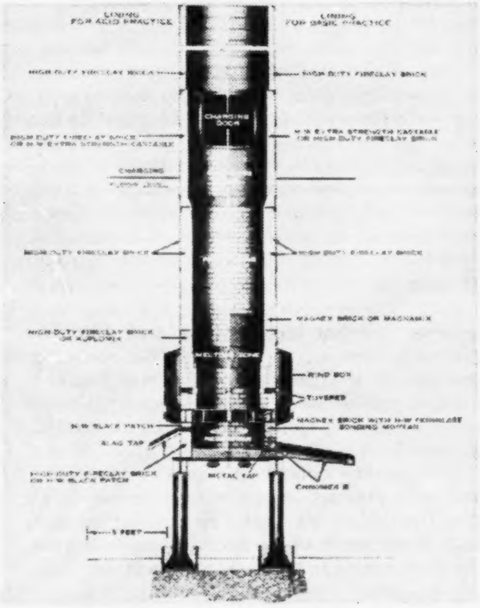
LINING FOR ACID PRACTICE
LINING FOR BASIC PRACTICE
HIGH DUTY FIRECLAY BRICK
HIGH DUTY FIRECLAY BRICK
CHARGING DOOR
CHARGING FLOOR LEVEL
HIGH DUTY FIRECLAY BRICK
HIGH DUTY FIRECLAY BRICK
MAGNEX BRICK OR MAGNAMIX
MELTING ZONE
WIND BOX
TUYERES
SLAG TAP
METAL TAP
5 FEET

Figure 4: Section of Typical Cupola

molten metal can be transferred to a converter such as shown in Figure 6. Limestone and oxygen may be employed to reduce impurity levels to that permissible for producing useful articles.

Selection of refractories for high temperature incineration should not be difficult. Since the process employed typical metallurgical and glass furnace practices, similar refractories can be used. The typical furnaces shown in Figures 4, 5, and 6 indicate the commercial refractories[11,12] that can be considered for these temperatures and corrosive conditions. In the cupola furnace, linings for either basic or acidic operation are indicated. In the incinerator, basic refractories would be considered in the metal area and acidic refractories in the glass area.

Utilization of Outputs From High Temperature Incineration

Incineration produces three outputs in material and energy:

(1) *Volatiles* which are chiefly carbon dioxide and water from the combustion of food wastes, paper and other organic matter, with smaller quantities of inorganic and organic chemicals as gases and fine particulate matter which are the potential pollutants of air. When refuse is incin-

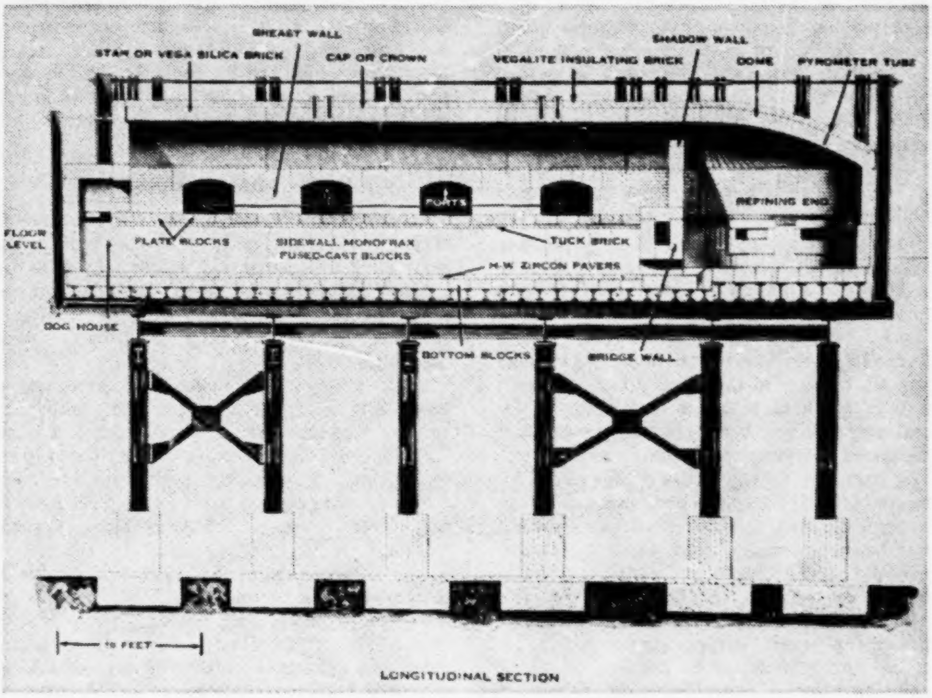
BREAST WALL
STAR OR VEGA SILICA BRICK
CAP OR CROWN
VEGALITE INSULATING BRICK
SHADOW WALL
DOME
PYROMETER TUBE
PORTS
REFINING END
FLOOR LEVEL
PLATE BLOCKS
SIDEWALL MONOFRAX FUSED-CAST BLOCKS
TUCK BRICK
H-W ZIRCON PAVERS
DOG HOUSE
BOTTOM BLOCKS
BRIDGE WALL
10 FEET
LONGITUDINAL SECTION

Figure 5: Typical Side-Port Glass-Tank Furnace

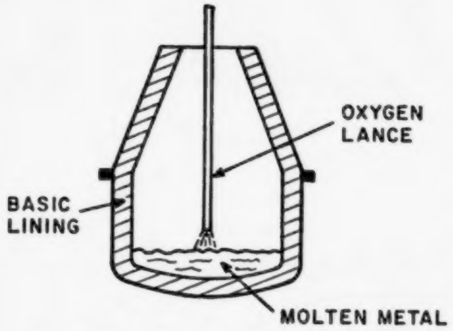
OXYGEN LANCE
BASIC LINING
MOLTEN METAL

Figure 6: Typical Metal Converter

erated, about 85% of it is typically converted to these gases.

(2) *Heat* to the extent of 5000 to 6000 BTU per pound of waste (compared to heat values in coal of up to 15,000 BTU/lb.)

(3) *Solid residues*, which are chiefly oxides and silicates (glassy forming substances) mixed with metallic constituents. These typically make up about 20% of the original refuse as shown in Table 4. This amount has been increasing with the popularity of throw-away packaging.

The market outlook for most iron scrap from low temperature incineration residue is poor. Changes in steel manufacturing technology have resulted in a lower demand for scrap metal and an increased demand for quality. Most iron from residues is not usuable as is because of excess contaminants. However, current research[2] may make this type of scrap usable for foundries.

TABLE 4
Typical Composition of City of Chicago Refuse

Refuse Components	% *By Weight*
Paper, paper products, wood, rags, etc.	73.7%
Garbage	2.3%
Plastics	0.9%
Cans: metal	8.0%
Glass	6.5%
Dirt	8.6%
	100.0%

IITRI's analyses have indicated that to justify the cost of high temperature incineration and to enable reduction of costs to municipalities in solid waste collection and disposal, it is essential to produce high value products from the solid residues. Operators of incinerators now have several choices. Crude, mixed metal and slag can be sold for roadfill at approximately $.50 per ton. The metal and slag can be separated and sold at higher values, e.g. as scrap metal at $30/ton and as lightweight aggregate at $5 to $8 per ton. IITRI's approach has been to develop the metal and ceramic outputs as fabricated products with high enough values to cover the cost of incineration. Figures 7 and 8 present potential products that can be made from high temperature incineration. Conversion of the slag into glass fiber is worth as much as $650 per ton. Similarly, the metal output is worth more as steel wool or as spherulized powders for powder metallurgy than as pig iron. The average value of steel wool for abrasive use is $800 per ton; atomized iron powder is valued at $280 per ton. If molten metal which has been removed from the coke and lime bed of the cupola furnaces and put through a slag separator can be used as a charge for a gray iron foundry, the metal is worth approximately $35/ton. The net cost of operating such a system may be further reduced by utilizing or selling surplus heat, steam, and possibly electric power.

The technology for producing high value products from the slags lies in that encompassed by glass and glass-ceramics manufacturing techniques which can be applied to the molten slag residue. Glass as well as metal products made by the high temperature incineration process are shown in Figure 9.

Solid Residue Composition

Information has accumulated from several recent studies on typical analyses of the solid outputs of municipal incinerators. In spite of obvious variations with season, climate, and region, compositions were relatively constant, attesting to the similarity of urban wastes throughout the U.S.

High temperature incineration produces a glassy slag which results from the melting of brick, concrete, stone, glass, and ash left from burning the volatile components of the refuse. The analyses of these slags are presented in Table 5. Silica, alumina, iron oxide, and calcia are the major constituents, similar to metallurgical slags from iron or copper production.

The composition of the metal portion has a high percentage of iron with lesser amounts of aluminum, copper, lead, zinc, and tin. A recent melt at IITRI of incinerated City of Chicago waste yielded a separated metal fraction containing over 95% iron, plus phosphorus, sulfur, and ar-

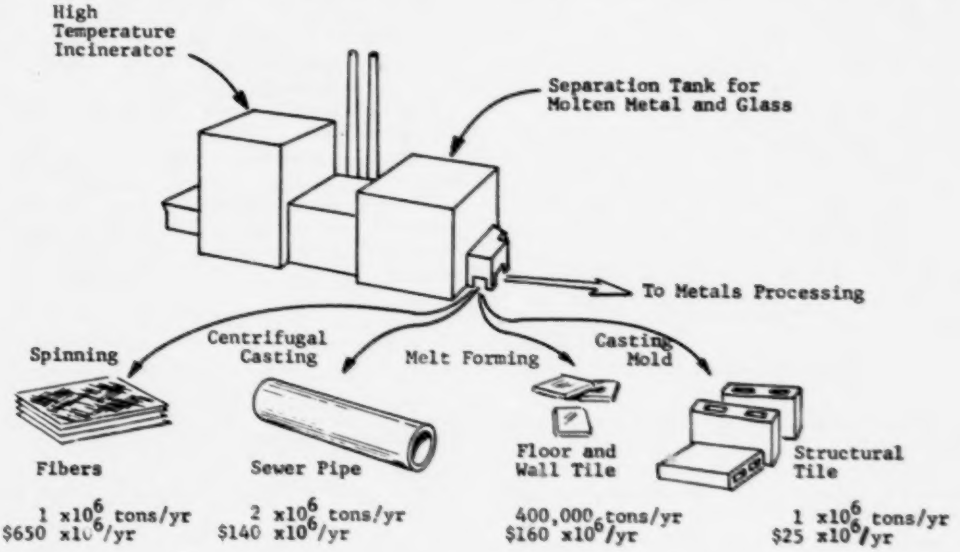

Figure 7: Proposed Glass Products from High Temperature Incineration and Marketing Potential

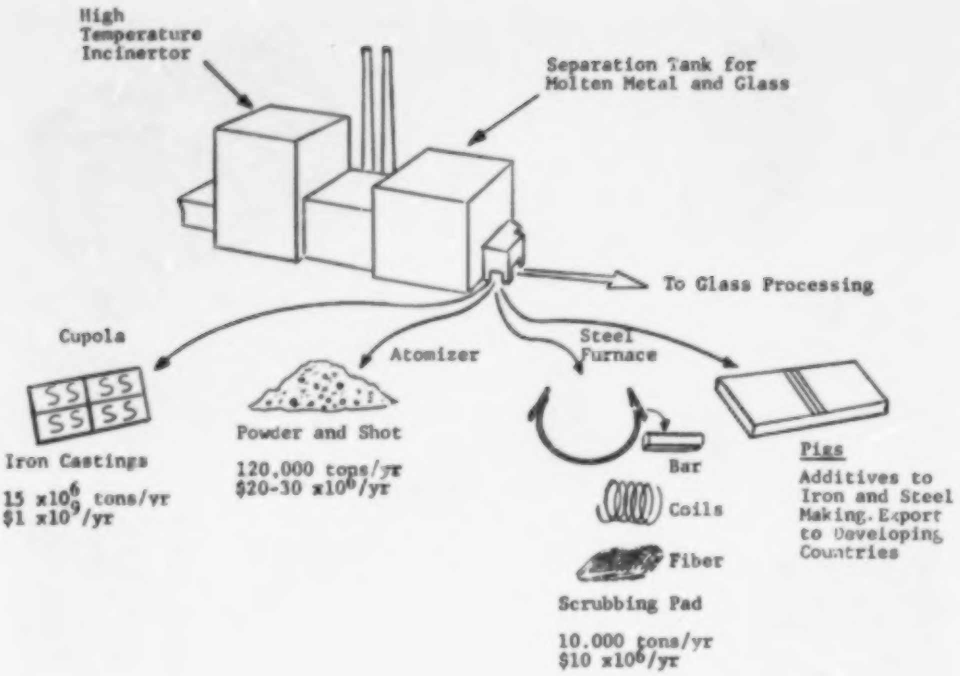
High Temperature Incinertor
Separation Tank for Molten Metal and Glass
To Glass Processing
Cupola
Atomizer
Steel Furnace
Iron Castings
15 x10⁶ tons/yr
$1 x10⁹/yr
Powder and Shot
120,000 tons/yr
$20-30 x10⁶/yr
Bar
Coils
Fiber
Scrubbing Pad
10,000 tons/yr
$10 x10⁶/yr
Pigs
Additives to Iron and Steel Making. Export to Developing Countries

TABLE 5
Chemical Analyses Cited for Slags from High Temperature Incineration

	Eggen & Powell	*Melt-Zit*	*Ferro-Tech*
SiO_2	61.9%	62.4	60
Al_2O_3	13.6	7.6	8
Fe_2O_3	3.7	FeO 5.2	4
TiO_2	-	0.7	-
CaO	6.6	14.2	17
MgO	2.0	3.3	5
BaO	0.2	-	-
ZnO	1.7	-	-
PbO	0.5	-	-
CuO	0.4	-	-
MnO	-	0.2	1
$Na_2O + K_2O$	9.4	3.8	3
SO_3	-	-	-
P_2O_5	-	0.7	-
Other	-	1.9	2
	100.0%	100.0%	100%

bon. Other high temperature incinerators have cited the metal analyses in Table 6.

Heat

TABLE 6
Analyses for Metallics from High Temperature Incineration

	Melt-Zit	*Ferro-Tech*
Fe	95.2	93.8
C	2.0 est	3.3
Si	1.6	2.1
Mn	0.2	0.3
Cu	0.3	0.3
Cr	0.3	0.1
Ni	0.2	-
S	0.1 est	0.1
	Mg. Al, Mg, Ti, Sn each less than 0.1	
		100.0%

Heat output from incineration is highly dependent on moisture level and composition. Table 7 presents a classification. Table 8 relates heat output to moisture level,[13] indicating that values ranging from 1000 to 8500 BTU for various types of typical urban waste are inversely related to the amount of moisture. An average value is 5000 BTU/lb.

A special case, polymers, are becoming an increasingly significant component of urban wastes. Clean, dry polymers may release 20,000 BTU/lb. on being combusted, but could introduce

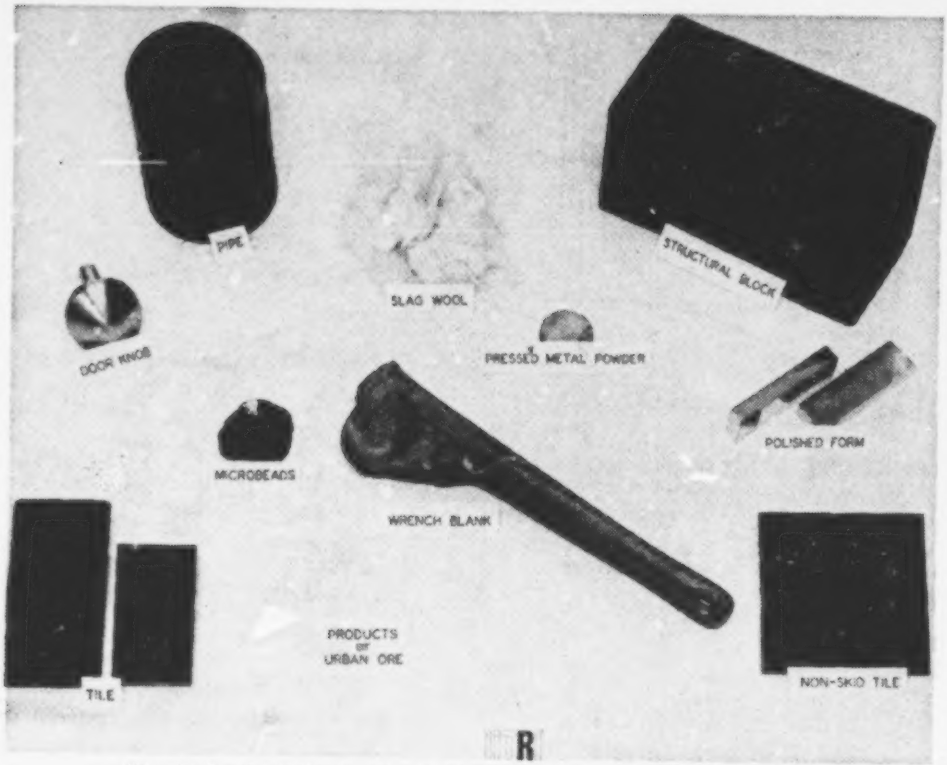
PIPE
SLAG WOOL
STRUCTURAL BLOCK
DOOR KNOB
PRESSED METAL POWDER
POLISHED FORM
MICROBEADS
WRENCH BLANK
TILE
PRODUCTS OF URBAN ORE
NON-SKID TILE

Figure 9: Experimental Products from High Temperature Incineration of Municipal Refuse

TABLE 7
Classification of Wastes and Heat Output[11]

Type of Waste	*Principal Components*	*Approximate Composition*	*Moisture Content*	*Btu/lb Combusted*
Fresh	Paper, wood, cardboard, plastic and rubber scraps	Fresh 100%	10%	8500
Rubbish	Paper, rags, cartons, wood scraps, floor sweepings	Rubbish 80% Garbage 20%	25%	6500
Refuse	Rubbish and garbage	Rubbish 50% Garbage 50%	50%	4300
Garbage	Animal and vegetable wastes	Garbage 65% Rubbish 35%	70%	2500
Animal solids and organic wastes	Carcasses, organs, solid organic wastes	100% animal and human tissue	85%	1000

problems with grate slagging and could contribute to air pollution on degradation.

About $3 per ton of raw waste can be recovered by selling steam at $1 per lb. of steam.[14] This is based on 1.4 pounds of steam being produced per pound of refuse.

TABLE 8
Estimated Values of Heat of Combustion vs Moisture Content

Moisture (%)	*Heat Value (Btu/lb)*
10	8500
25	7000
50	4500
70	2500
85	1000

SUMMARY

In summary, as shown in Figure 10, high temperature incineration offers a means of recovering the cost of municipal refuse operations and a new source of raw materials. Its successful development can create a vast new industry.

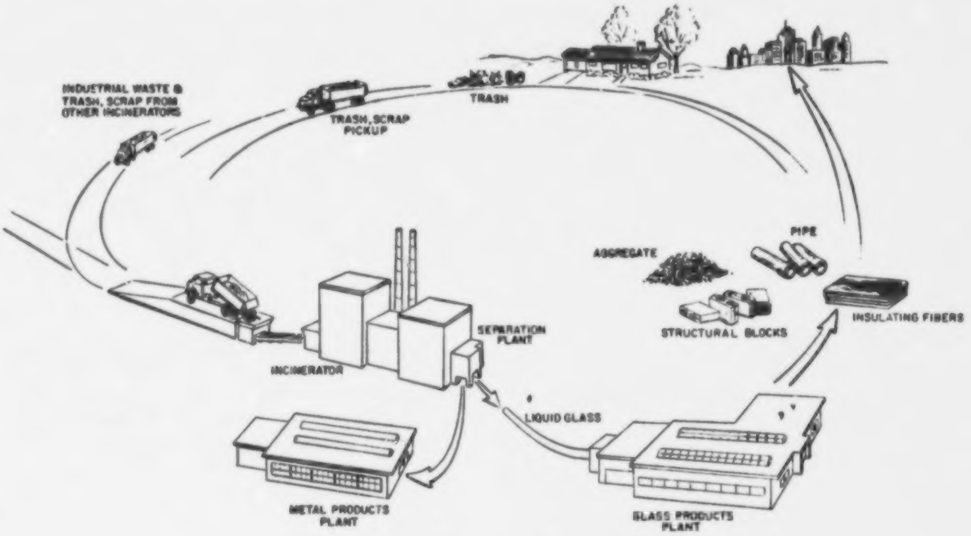

Figure 10: Closed Loop Cycle for Municipal Refuse Utilization

REFERENCES

1. Michaels, A. *The American City*, 83, 5 (1968).

2. Kenahan, C. B., et al. "Composition and Characterization of Municipal Incinerator Residues," Report No. 7204, Bureau of Mines, U.S. Dept. of Interior, 1968.

3. Puglisi, E. A. and W. R. Loftus. 'Air Pollution, Incineration, and the Construction Industry, Part III - The Incinerators," *Construction Review*, 15, 10, 4 (1969).

4. "The National Solid Waste Survey, an Interim Report," presented at the 1968 Annual Meeting, Environmental Control Association, U.S. Dept. of Health, Education and Welfare (1968).

5. Kaiser, E. R. "An Incinerator Designer Considers Refractories," *Proceedings Fifth Annual Symposium on Refractories*, St. Louis Section of the American Ceramic Society (April 1969).

6. Eggen A. and O. A. Powell, Jr. "Feasibility Study of a New Solid Waste System," University of Hartford, Hartford, Conn., DUST/TR-6701 (Nov. 1967).

7. Kaiser, E. R. "Evaluation of the Melt-Zit High Temperature Incinerator," U.S. Dept. of Health, Education and Welfare Grant No. D01-UI-00076, *Operation Test Report*, for City of Brockton (August 1968).

8. Mihm, Y. "The FLK Slagging Incinerator A New Design Concept," Davo Corporation, 3600 Neville Road, Pittsburgh, Pa. 15225, Paper presented to Design Committee of ASME Incinerator Div., N.Y., N.Y. (March 1969).

9. "Ferro-Tech Total Incineration," *Company Report*, Ferro-Tech Industries, 1742 N. Highland Road, Pittsburgh, Pa. 15228 (July 1969).

10. "The Torrax Solid Waste Disposal System," *Company Report*, Torrax Systems, Inc., 641 Eric Ave., N. Tonawanda, N.Y. 14120.

11. *Modern Refractory Practice*, Harbison Walker Refractories Company, William Feather, Cleveland (1961).

12. Norton, F. H. *Refractories*, 4th Ed., McGraw-Hill, New York (1968).

13. Essenhigh, R. H. 'Burning Rates in Incinerators," *Proceedings 1968 National Incinerator Conferenc* (1968).

14. Day and Zimmermar, Engineers and Architects. "Special Studies for Incinerators for Government of the District of Columbia," Report SW-1d, U.S. Dept. of Health, Education and Welfare, Grant No. D01-SW-00038-01, Public Health Service, Pub. No. 1748 (1968).

Air Pollution Control Technology for Incinerators

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INTRODUCTION

Incinerators, though contributing only a small percentage of the total national air pollution load, are a major source of emission near population centers. As public demands for clean air grow, increasing numbers of municipal governments are evaluating the air pollution characteristics of existing incinerators - both municipal and industrial - and are seeking new standards of performance for application to these and future plants.

Selection of air pollution control (APC) devices to meet these new incinerator effluent standards should be based on consideration of a number of factors, including the following:

- The nature of the waste being burned;
- The design of the incinerator furnace;
- The operating practices for the incinerator furnace;
- The nature and quantity of the pollutants as they relate to the above;
- The control efficiency and cost (capital and operating) of alternative APC devices for the pollutants so specified; and
- The present or future emission codes which must be met.

These factors should be fully exploited in the design of specialized waste disposal systems and for the modification or upgrading of existing facilities. This has too often not been the case in the past.

The techniques available for controlling the rate of emission from industrial and municipal incinerators will be the subject of this paper. Particular emphasis will be placed on the need, in considering air pollution control, to treat the incineration system as a whole with full consideration of the nature of the waste burned and of the design and operation of *both* the combustion chamber and the APC device. Included will be a review of the control of emission rate achievable by modification of combustion chamber design/operation and of the dependence of the performance of APC devices on the specific nature of the pollutants leaving the combustion chamber - two important factors that are often overlooked in the selection of APC systems. APC system costs and cost effectiveness will also be briefly discussed.

Comparatively little data are available on the air pollution from incinerators burning industrial wastes. The presentation here will, therefore, draw heavily from the data on emission rates and control technology obtained for refuse incinerators, based on an extensive study sponsored by NAPCA at Arthur D. Little, Inc. and supplemented with data for coal-fired process and utility boilers utilizing stationary and traveling grate stockers. Fortunately, the same fundamental physical and chemical principles control the combustion of industrial wastes, refuse, and coal, so that generalizations on refuse and coal combustion will have broad applicability to most industrial solid waste incineration systems.

Emission Factors for Incinerator Combustion Chambers

Particulate Emission

Excessive particulate emission has been the source of the majority of complaints made against incinerators as a consequence of either the high rate of dust deposition in the vicinity of a unit or the production of aesthetically displeasing plumes. The amount, composition, and size distribution of the emitted particulate depend on the waste being burned and the design and operation of an incinerator. Some generalizations applicable to the nature of the emission leaving the incinerator furnace follow.

Mineral Particulate

Mineral particulate, here defined as the incombustible fraction of fly ash, is composed mainly of mineral matter in waste that is entrained by the combustion air or combustion products. Oxidation of metals and the subsequent volatilization or entrainment of the oxides also contribute to the mineral particulates, but for mixed wastes, this usually contributes only a small fraction of the total particulate loading.

From consideration of the velocities that will entrain particles of different equivalent spherical diameters (Figure 1), it is estimated that the range of undergrate velocities usually encountered in incinerators will entrain particles with equivalent spherical diameters smaller than 70 to 400 μ from the grate. Wide variations in emission of mineral particulate can, therefore, be expected, depending on the amount and size distribution of the ashed residue of the waste and on undergrate velocity. Estimates of the fraction of the fine ash content of waste that is entrained off the grate may be obtained from consideration of data on three widely different grate stockers: a German municipal incinerator,[1] a Public Health Service test incinerator operated on synthetic refuse,[2] and an asphalt-saturated felt roofing[3], and coal-fired stokers.[4] Despite the very wide variation in incinerator type and material burned (the ash content varied from 2.5 to 50 percent), the fraction of the ash carried over for these units was in the range of 10 to 20 percent, except for some runs made by the PHS with practically no underfire air.

This leads to a useful rule. In the absence of any data, a fair estimate of the total mineral particulate loading of the gases leaving the furnace is 15 percent of the ash content of the waste. (Massive residues, such as glass and metals, should not be included in the calculation of ash content.)

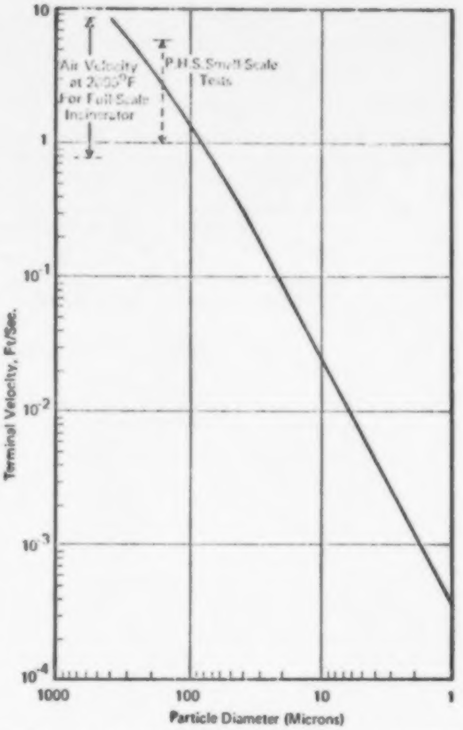


Figure 1: Particle Fluidization Velocities (Terminal Velocities)

From the ultimate analysis of some industrial wastes (Table 1), it may be seen that material, such as polyethylene, with a low ash content will yield very low emissions of mineral particulate in contrast with materials such as filled plastics or glossy magazines, yielding a significant fraction of fine ash.

Some control over particulate emission may be obtained from regulation of the underfire air rate. The reduction in particulate emission that can be achieved by this technique can be estimated from the tests by Walker and Schmitz[5] and by the Public Health Service.[6] These indicated that when more than 20 percent of the air requirements were supplied under the grate, the rate of emission of mineral particulate was proportional to the 0.55 power of the air velocity. In this range, a two-fold reduction in air velocity will produce an approximately 30 percent reduction in emission rate.

Entrainment of mineral particulate, however, cannot be eliminated completely by the elimination of underfire air since the buoyancy of the

TABLE 1
Ash Content of Selected Industrial and Municipal Wastes*

Ash Content	*Material*
0 - 2	Polyethylene film, kraft paper, waxed milk cartons, vegetable food wastes, semi-cured tubes, nylon fabric and yarn, newspaper
2 - 5	Banbury rubber scrap, vinyl scrap, plastic-coated paper, lawn grass, balsam spruce, ripe tree leaves, cooked meat scraps
5 - 10	Vinyl-coated fabric, expanded Ensolite, uncured frictional duck, cured flash and molded goods
10 - 15	Vinyl-coated felt, raw batch stock, junk mail, wire-fraid hose
20 - 25	Shoe leather, rubber-coated fabric, cloth uppers, ensolex trim, trade magazines
25 - 30	Foam scrap, heel and sole composition
>30	Cloth-backed foam, die strip, rubber tape

*Abstracted from compilations by R. B. Engdahl and E. R. Kaiser.

combustion gases will induce an air flow that will produce a minimum particulate emission. From dimensional analysis, it can be shown that, for a buoyancy driven flow, the velocity V of the induced air is proportional to $\sqrt{L \, \Delta\rho \, / \, \rho \, g}$, where L is a characteristic length of the combustion chamber, $\Delta\rho$ is the difference in density between the colder entrained gases and the hot combustion products, ρ is the mean density of the combustion products, and g is the gravitational acceleration. Entrainment of particulate by buoyancy driven flows will, therefore, increase with furnace size and flame temperature. An additional factor that enhances particulate emission is agitation (stoking) of the burning waste, but the magnitude of this factor has not been quantitatively established.

Combustible Particulate

Combustible particulate consists of char (blackbirds) entrained from the grate, soot (black smoke) produced by the thermal cracking of pyrolysis products before these have been mixed with sufficient oxygen to complete their combustion, and an aerosol (white smoke) produced by the quenching of pyrolysis products before they have reacted. All three are highly visible and have a nuisance value in excess of their contribution to the total particulate emission rate.

Char formed from paper or sheets of other carbonizable material has a high surface-to-volume ratio and is, therefore, entrained at relatively low velocities in amounts that depend on the make-up and degree of agitation of the refuse bed. Inert material in the bed has a beneficial effect of keeping elements of char from being entrained. No quantitative estimate of the emission rate of charred waste components is available, but it is believed to be a small fraction of the total particulate emission.

The second source of combustible material, soot, is usually the most significant one. Soot particles, once formed, are relatively difficult to burn, and - as a consequence of their characteristically small dimensions - are difficult to collect. The best form of control of black smoke is, therefore, the prevention of soot formation. This can be achieved by the rapid mixing of the pyrolysis gases with sufficient air to complete their combustion, since it has been shown that with perfect mixing, little soot is formed even under fuel-rich conditions. For example, Wright[7] has found that for a wide range of hydrocarbons burned in a well-stirred reactor, the atomic ratio of oxygen to carbon, where soot was first detected, ranged from 1.35 to 1.81 - well below the stoichiometric ratio of 2.00. The practical significance of these results is that soot formation may be prevented by the proper design and placement of overfire air or steam jets, as was emphasized in the early studies at Battelle under Engdahl.[8]

The mechanism of soot formation is so complex, however, that the amounts of combustible particulate that have a furnace chamber cannot be reliably estimated, although some rough guides are given by Field et al.[9] The amounts of soot formed are a measure of the poor mixing conditions in a chamber and are expected to be greatest when a furnace is overcharged or when a waste having a high fraction of volatile carbon (total minus fixed carbon) is burned. Under normal operating conditions, the average combustible fraction of the particulates leaving combustion chambers of municipal incinerators is found to be about 15 percent;[10] but because soot forms as submicron particles, it is difficult to collect, and the fraction of combustibles in the particulates leaving air pollution control devices can be considerably higher.[10]

High percentages of combustibles in the particulates leaving a combustion chamber are encountered during the incineration of wastes that generate a large volume of carbon-rich pyrolysis gases. For example, tests carried out by the PHS[3] on an experimental incinerator, using as fuel asphalt-saturated felt roofing, resulted in emission of particulates with an average combustible content of 88 percent. Emission rates for combustible particulates will, of course, vary widely; reported values have ranged from 0.3 lbs./ton waste for cellulosic materials to about 80 lbs./ton for the asphalt-saturated roofing. For contemporary, continuous-feed municipal incinerators, an average emission of 3.9 lbs. combustible/ton refuse has been found,[10] a figure which corresponds to about 20 percent of the total particulate. For coal-fired stokers, excluding spreader-stokers, the limited data[11] suggest that on the average, 40 percent of the fly ash is combustible; but the spread in measured values was large.

The third type of combustible particulate emission is the aerosol of unreacted hydrocarbons which is formed when the pyrolysis products evolved on the grate are cooled and condensed before mixing with hot furnace gases. The white smokes that are produced usually consist of fine particles ($< 2\,\mu$) which are difficult to collect. Such emission, however, is relatively infrequent and can be eliminated by either after-burning or the adjustment of the air flow to a furnace to provide better overbed mixing.

Gaseous Emission

In the past, gaseous pollutant emissions from most incinerators were given little attention. However, public concern regarding air pollution has resulted in renewed interest in all facets of emission, including gaseous species. These pollutants can be considered in three categories:

- Combustible pollutants (hydrocarbons and carbon monoxide);
- Non-combustible pollutants associated with the combustion process itself (nitrogen oxides); and
- Non-combustible pollutants released by the combustion process but directly arising from specific components (hydrogen chloride, sulfur dioxide, hydrogen fluoride, volatilized metals).

Hydrocarbons and Carbon Monoxide

The presence of hydrocarbons and carbon monoxide in the stack gases of incinerators is principally a consequence of poor mixing between pyrolysis gases and air. Because of the difficulty of achieving good mixing on a molecular scale, incomplete combustion of carbon monoxide has sometimes been erroneously attributed to limitations of the kinetics of the reaction. Evidence to the contrary is provided by the studies on well-stirred reactors in which premixed fuel-air mixtures are fed into the reactors through small holes yielding high velocity, often sonic, jets which promote an intense mixing of the fuel-air mixtures with their products of combustion. The interesting conclusions derived from the use of well-stirred reactors[12,13,14] are the following:

(1) The kinetics of oxidations for a large number of fuels are so fast that volumetric heat release rates of 10^6 to 10^9 BTU/(ft.^{3}) (hr.) are achievable over the temperature range of 2000 to 3000°F;

(2) The reactions of the hydrocarbons or ketones studied are very fast relative to that of the carbon monoxide intermediately formed in the reaction, and therefore, the gases in the reactors contain much larger concentrations of carbon monoxide than of the unreacted fuel; and

(3) The rate of burnout of the carbon monoxide, which provides the rate limiting stop, is given by the following:

$$\frac{df_{co}}{dt} = 1.8 \times 10^{10} \exp[-25{,}000/RT]$$

$$f_{co} f_{o_2}{}^{1/2} f_{H_2O}{}^{1/2} (P/RT) \qquad (1)$$

where F_{co} , f_{o_2} f_{H_2O} are the mole fractions of CO, O_2, and H_2O; T is the absolute temperature in °K; and (P/RT) is in a moles/liter; and t is in seconds. The water vapor concentration is of importance because the principal reaction in the oxidation of CO is that with hydroxyl radicals. The above rate equation should not be used much outside the temperature range (1800-3000°F) of the data to which it was fitted.

The application of the above conclusions to incinerators is of interest. For the values of temperature, oxygen, and water vapor concentrations representative of good incineration practice, the above equation yields for the time required to reduce the carbon monoxide concentration to less than one hundredth of one percent a value of the order to a millisecond. It can, therefore, be concluded that, if turbulence above a fuel bed is high enough to provide perfect mixing, no CO should be found in the exit gases and complete reaction of the pyrolysis products could be achieved in a small fraction of the volume presently recommended for the combustion chamber. Based on the well-stirred reactor studies, it is also expected that, because CO burns so much slower than other fuel elements, carbon monixide will be detected in larger quantities than hydrocarbons in incompletely burned flue gases.

The above conclusions are consistent with observations on municipal and experimental incinerators. A survey[10] on municipal incinerators conducted for NAPCA by ADL shows many units with CO concentrations in the stack gases below the detection limit. The average value for modern systems, however, was 29.4 lbs./ton of refuse burned. The ADL study also showed that for units which emit appreciable amounts of hydrocarbon and carbon monixide, the weight ratio of hydrocarbon to carbon monoxide is, on the average, about one thirteenth (Figure 2). Further evidence supporting the conclusions that improper mixing and not chemical kinetics are responsible for the incomplete burnout of the carbon monoxide is provided by the studies of Mayer,[15] Woodruff and Larson,[16] and Weintraub, Orning and Schwartz.[17] These references show that considerable stratification occurs above fuel beds of coal and refuse, with part of the flue gas carbon monoxide-rich and the remaining oxygen-rich. (Caution should be used in interpreting data showing the coexistence of fuel and oxygen at furnace temperatures, since samples near a flame or other stratification front will be withdrawn alternately from both sides of the front due to the gross fluctuations in the front position.)

Nitrogen Oxides

Nitric oxides are formed in furnaces by the oxidation of either atmospheric nitrogen or the bound nitrogen in the pyrolysis products of waste. The kinetics of oxidation of atmospheric nitrogen is slow below 3200°F, so that formation of nitric oxide by this mechanism is limited to the high temperature zone about the flame front. Experiments by Shaw and Thomas[18] have shown that nitrogen-containing compounds (such as butylamine, pyridine, methyl cyanide), when burnt in premixed flames, yield significant amounts of nitric oxide at temperatures as low as 1650°F. It is still a matter of speculation, however, as to whether nitrogen in fuel is an important source of nitric oxides for diffusion flames, such as those found above the fuel bed in an incinerator. Nitric oxide formation by either of the above mechanisms is expected to be enhanced by high temperatures and high percentages of excess air. Data on nitric oxide formation in incinerators support this claim. In addition, the data obtained on a test incinerator by the PHS for both synthetic refuse and an asphalt-saturated felt roofing was found to be better correlated with the heating value of the fuel than the weight; this supports the postulate that the formation of nitric oxide is limited by the temperature dependent chemical kinetics. In addition, it was found that the nitric oxide formation decreases as the percent of underfire air increases, supporting the postulate that the nitrogen oxides are formed in the flame zone above the bed. Emission factors for a number of tests and municipal incinerators (Figure 3) can be adequately correlated by the following equation:

$$\text{lb. NO}_x\text{ hr.} = \left[\frac{\text{Heat Release Rate } (10^6 \text{ BTU/hr.})}{4.6}\right]^{1.18} \quad (2)$$

This method of correlation was suggested by Woolrich[19] who applied it to furnaces fired by conventional fuels and obtained for the constant in the denominator of the right-hand side values of 6.6 for gas, 4.44 for fuel oil, and 3.8 for coal. It must, however, be recognized that this correla-

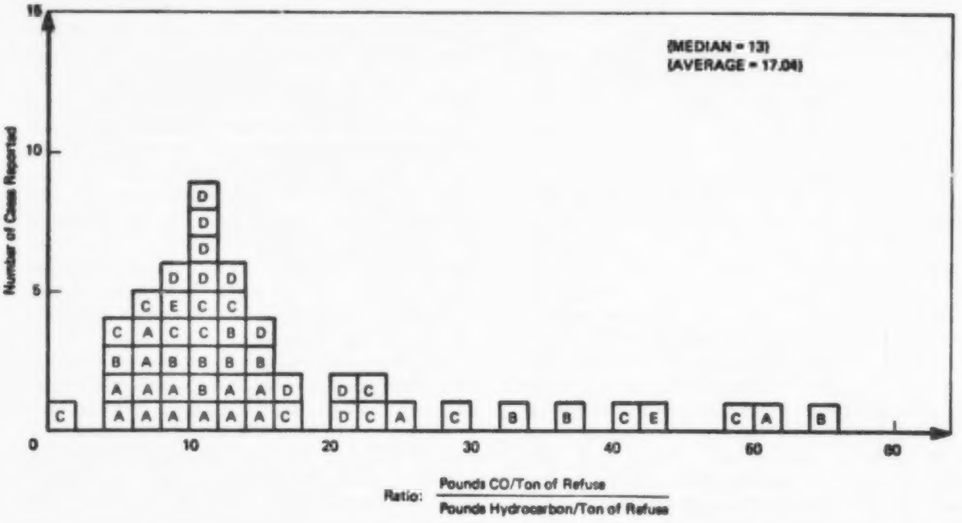


Figure 2: Histogram of Ratio of Emission Factors for Carbon Monoxide and Hydrocarbons

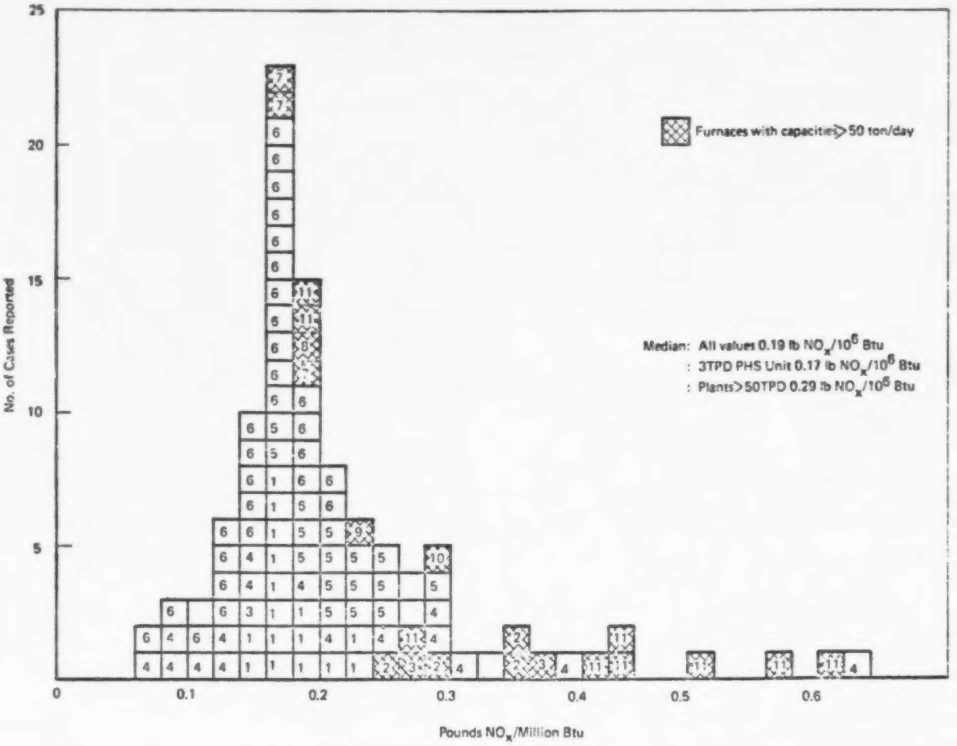


Figure 3: Emission Rate: Pounds NO_x (as NO_2) Per Million BTU

tion provides only rough estimates since factors, such as furnace heat loss and excess air which are known to influence NO production, are not taken into account.

Hydrogen Chloride

The emission of hydrogen chloride (HCl) from municipal and industrial incinerators is a matter of increasing public concern. In addition to its air pollutant characteristics, HCl can cause corrosion in scrubbers and stacks and, for plants practicing heat recovery, can corrode boiler tube surfaces. HCl appears in incinerator effluents as a combustion product of halogenated polymers, primarily polyvinyl chloride (PVC) and polyvinylidene chloride. In municipal waste, these materials appear in low concentrations as housewares, textiles, packaging, toys, etc. Industrial waste streams, however, may contain high concentrations of these polymers as trimmings, product rejects, packaging, and so forth. Incineration of PVC yields 1,180 pounds of HCl per ton of pure resin burned. An estimate may be made, therefore, of the HCl furnace emission factor by determining the PVC content of the waste. For typical domestic and commercial solid waste, the data shown in Table 2 indicate the present and forecast HCl emission rate based on emissions of national average refuse compositions.[10]

It is possible that absorption of HCl on fly ash within the furnace or the use of wet air pollution control systems with good mass transfer characteristics may reduce stack emissions of HCl. Acid gas absorption by ash materials has been noted by Kaiser.[20] Wet collectors operating on flue gas containing high concentrations of HCl, however, will experience severe corrosion problems due to the acid characteristics of the resulting scrubber wastewater and to chloride ion effects. Water treatment to neutralize acidity and careful choice of materials of construction will be necessary in order to insure acceptable scrubber life.

Sulfur Dioxide

The importance of sulfur oxides as air pollutants is well recognized. Municipal incinerators,

TABLE 2
Anticipated Growth Patterns of PVC Pure Resin In Average Refuse and Associated HCl Emission*

Year	*% Plastics in Refuse***	*% PVC in Plastics*	*HCl Emission Factor lb HCl Per Ton of Refuse****
1968	1.1%	7.8%	0.99
1970	1.3	10.0	1.50
1975	1.8	10.6	2.20
1980	2.7	8.7	2.71
1990	3.5	10.9	4.41
2000	4.2	11.2	5.44

* Source: ADL Estimates
** As-discarded basis - semi-seasonal state
*** Based on quantitative conversion of the chloride in PVC to HCl

however, contribute little to urban sulfur oxide pollution, as the sulfur content of typical refuse approximates only 0.1%.[10] Indeed, the low sulfur concentration in municipal refuse has suggested the use of this fuel as a partial replacement for high sulfur fuels in utility applications.

For municipal refuse, the above-mentioned sulfur content corresponds to an emission rate of 3.94 pounds of SO_2 per ton of refuse burned. Based on comparisons with fossil fuel burning installations, 1-3% of the sulfur may appear as SO_3. For industrial refuse, of course, the SO_2 emission may differ greatly from this value depending upon the sulfur content of the waste materials. An assessment of waste composition is necessary to determine sulfur oxide emissions from incineration of these waste streams.

It has been suggested by Kaiser[20] that 3/4 of the sulfur present in municipal refuse is absorbed and fixed as a solid by alkali oxides in the grate residue and fly ash. Kaiser's analysis is based upon several sets of paired refuse and residue analysis data but very limited gas analysis data. Uncertainties in the material balances and the lack of definitive gas composition data do not discount Kaiser's hypothesis, but rather emphasize the need for new data in order to quantity the importance of this mechanism of in-furnace SO_2 abatement.

Other Caseous Pollutants

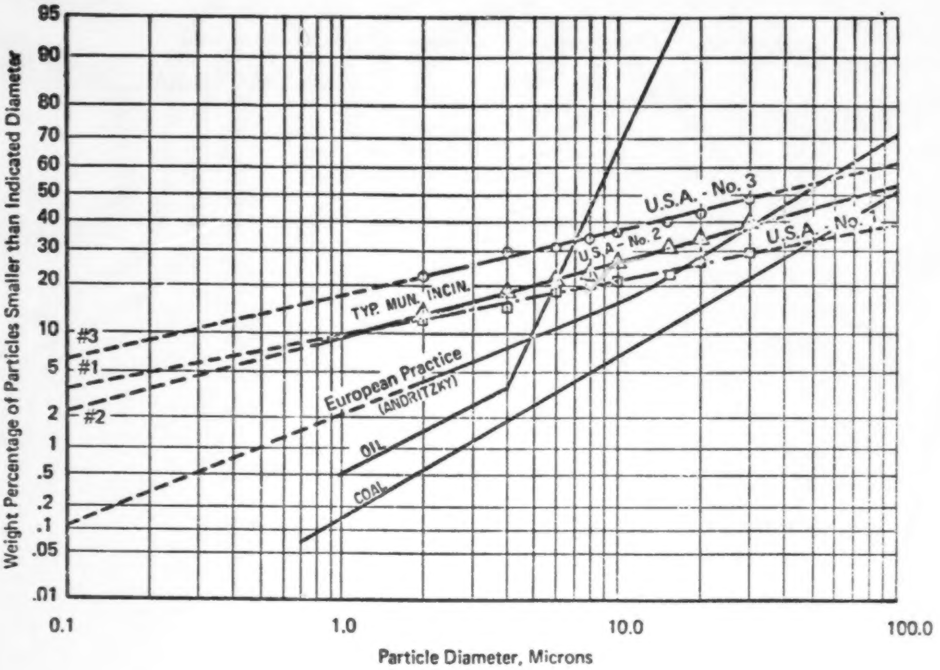
Municipal and industrial solid waste contains a number of materials which produce pollutant streams in addition to those discussed above. For example, fluorinated hydrocarbons (present in low concentrations in municipal wastes) result in hydrogen fluoride emissions, or selenium (small quantities of which are found in paper and other cellulosic wastes) yields selenium oxides in the flue gas stream; lead (found in the solder used in tin cans) yields a lead oxide fume; zinc and cadmium (galvanizing metals) volatilize and oxidize to form a fume. The amounts of these materials evolved will depend on the waste composition. Only minor quantities of these pollutants arise from the incineration of municipal solid wastes. Industrial wastes, however, may contain substantially higher concentrations of the toxic elements mentioned above and must be evaluated on a waste-by-waste basis.

Air Pollution Control for Incinerators

Historically, the primary concern in air pollution control (APC) for municipal incinerators has been the reduction of particulate emissions. Combustible pollutant emissions, as discussed below, are best controlled by improvement of the combustion process within the furnace itself; and, at the present time, the emission rates of gaseous pollutants, such as nitrogen oxides, hydrochloric acid, and sulfur dioxide, are small. Future changes in refuse composition or operating practices could shift these priorities for municipal waste incinerators; and indeed, for industrial incinerators, abatement emphasis may well be placed on non-particulate emissions, particularly for halogenated polymers with a low ash content.

Mineral Particulate Emission Control

In order to evaluate the performance needs of APC system for the removal of particulate species, a furnace effluent composition must be established. Of particular importance is the description of the particle-size distribution of the mineral ash material. Figure 4 shows three furnace emission particle size distributions for three U.S. in-



Sources: European: Andritzky, M., Brennstoff-Wärme-Kraft *19*(9), 436(1967)
U.S.A.: Walker, A B and Schmitz, FW, Proc. 1966 ASME Nat'l. Incin. Conf., pp 64-73

Figure 4: Particle Size Distributions of Furnace Effluents

cinerators:[5] data by Andritzky[21] on European ash, data on particulate emissions from oil-fired utility boilers,[11] and data for pulverized coal-fired boilers.[4] Since the particulate collection efficiency of APC equipment is a strong function of particle size, it can be seen that a given APC system would show quite different integral efficiencies for the same inlet loadings of these various fly ash materials.

Table 3 after Stairmand[22] suggests the magnitude of the effect of particle size on collection efficiency for a variety of common APC equipment. Clearly, to assure that a given system will yield a given effluent loading, the particle-size distribution of the inlet dust must be specified in addition to the total inlet dust loading. While this approach to efficiency evaluation is well recognized, overall efficiencies are too often quoted for various APC designs without regard to specification of the particle-size distribution.

In evaluating control effectiveness for municipal incinerator mineral particulate, the inlet dust particle-size distribution of the dust indicated as "U.S.A. No. 2" on Figure 4 was selected. It has been noted, however, that design and operating effects can modify the distribution for any specific system (e.g. by better combustion which destroys a fraction of the small combustible particulate or atypical refuse compositions yielding alternate mineral ash particle-size distributions). Indeed, modification of emission characteristics by changing operating parameters may provide a means to reduce the "efficiency" requirements placed upon the APC device.

The anticipated collection efficiencies for various APC systems for the nominal dust size distribution selected above are shown in Table 4. The values shown in this table were developed from a theoretical evaluation of APC performance (as a function of particle size) and confirmed, where possible, with APC system performance data. It can be seen that systems using contemporary APC technology can obtain almost any desired degree of particulate removal.

TABLE 3
Efficiency of Dust-Arresting Equipment at Various Particle Sizes

Equipment	*Percentage Efficiency At* 50 μ	5 μ	1 μ
Inertial collector	95	16	3
Medium-efficiency cyclone	94	27	8
Cellular cyclone	98	42	13
High-efficiency cyclone	96	73	27
Tubular cyclones	100	89	40
Jet-impingement scrubber	98	83	40
Irrigated cyclone	100	87	42
Self-induced-spray deduster	100	94	48
Spray tower	99	94	55
Fluidized-bed scrubber	>99	98	58
Irrigated-target scrubber	100	97	80
Electrostatic precipitator	>99	99	86
Disintegrator	100	98	91
Irrigated electrostatic precipitator	>99	98	92
Annular-throat scrubber - low energy	100	>99	96
Venturi-scrubber - medium energy	100	>99	97
Annular-throat scrubber - medium energy	100	>99	97
Venture-scrubber - high energy	100	>99	98
Shaker-type fabric filter	>99	>99	99
Low-velocity bag filter	100	>99	99
Reverse-jet fabric filter	100	>99	99

Combustible Particulate

Although the best control of combustible particulate is by good mixing of the pyrolysis products with combustion air, the design of effective overfire jets is difficult, particularly for unsteady operation. It is, therefore, desirable to provide overbed conditions that will cause any soot particles formed to burn out. The design requirements for the burnout of carbonaceous particles can be determined from a consideration of the rates of oxygen diffusion to the carbon particle surface and the chemical kinetics of carbon burning. The time for burnout of the particles can be shown to be inversely proportional to the oxygen particle P_{O_2}, to increase with particle size, and to decrease with increasing temperature. The time in seconds is approximately given by the following equation:

$$t = \frac{1.0}{P_{O_2}}\left[\frac{d}{\exp\left[\frac{-35,000}{R}\left(\frac{1}{T} - \frac{1}{1000}\right)\right]} + \frac{d^2}{4.75 \times 10^{-5} T^{0.75}}\right] \quad (3)$$

where d is the particle diameter in centimeters; P_{O_2}, the oxygen partial pressure in atmospheres; R, the gas constant in calories/degrees Kelvin; and T, the temperature in degrees Kelvin. The first and second terms in the brackets represent the resistances due to chemical kinetics and diffusion, respectively. For the temperatures in incinerators, the rate is usually limited by the chemical kinetics. Some uncertainty exists concerning the kinetics of carbon and soot combustion, but this does not influence the general conclusions de-

TABLE 4
APC System Average Control Efficiency

APC Type	APC System Removal Efficiency (weight percent)								
	Mineral Particulate	*Combustible Particulate*	*Carbon Monoxide*	*Nitrogen Oxides*	*Hydro-carbons*	*Sulfur Oxides*	*Hydrogen Chloride*	*Polynuclear Hydrocarbons*[b]	*Volatile Metals*[c]
None (flue settling only)	20	2	0	0	0	0	0	10	2
Dry Expansion Chamber	20	2	0	0	0	0	0	10	0
Wet Bottom Expansion Chamber	33	4	0	7	0	0	10	22	4
Spray Chamber	40	5	0	25	0	0.1	40	40	5
Wetted Wall Chamber	35	7	0	25	0	0.1	40	40	7
Wetted, Close-Spaced Baffles	50	10	0	30	0	0.5	50	85	10
Mechanical Cyclone (dry)	70	30	0	0	0	0	0	35	0
Medium Energy Wet Scrubber	90	80	0	65	0	1.5	95	95	80
Electrostatic Precipitator	99	90	0	0	0	0	0	60	90
Fabric Filter	99.9	99	0	0	0	0	0	67	99

(a) Assumed primarily < 5μ
(b) Assumed two-thirds condensed on particulate, one-third as vapor
(c) Assumed primarily a fume < 5μ

rived from application of the above equation.

From the illustrative calculations shown in Figure 5, it may be seen that for different amounts of excess air and different temperatures, a range of particle burnout times will be experienced. These calculated values are useful in specifying the residence time requirements for the design of after-burners. An after-burner that provides a residence time of 0.3 seconds at 2000°F with 2% oxygen, for example, will burn out all particles smaller than 7 microns.

Hydrocarbon and Carbon Monixide

From examination of the kinetic expression for CO burnout, which usually is the limiting step in the burnout of hydrocarbons, it can be seen that essentially complete burnouts can be achieved in a fraction of a second if the combustion gases are raised to temperatures above 1500°F. The importance of good mixing between the partially burned pyrolysis products and the air and fuel in an after-burner cannot be overemphasized.

Non-Combustible Gaseous Pollutants

Evaluation of APC system performance in controlling gaseous pollutant emission should also be made in reference to a specific inlet gas composition. The data shown in Table 5 summarize the limited available data on the composition of the effluent gases from conventional municipal incinerators. In consideration of the vast differences in waste composition characteristic of industrial incinerators, attention should be given to evaluation of the nature of the waste burned to develop realistic gas compositions for these systems.

In dry collectors (cyclones, precipitators, baghouses, etc.), little collection of gaseous non-combustible pollutants can be expected. Possible exceptions exist for the removal of polynuclear hydrocarbons which have condensed on particulate matter (perhaps as much as two-thirds of that emitted from the furnace)[23] and the removal of SO_3 noted in tests on a pilot baghouse unit.[10]

Wet collectors (wet baffles, wet cyclones, and the various "scrubbers") can and do remove at least a fraction of the gaseous pollutants formed in incinerators. Wet collectors are, in general, less effective than a single equilibrium contact (theoretical stage), and, as an approximation, maximum performance can be calculated on this basis. Indeed, since most wet scrubbers are co-current flow devices, they can at best only approach one theoretical stage in performance.

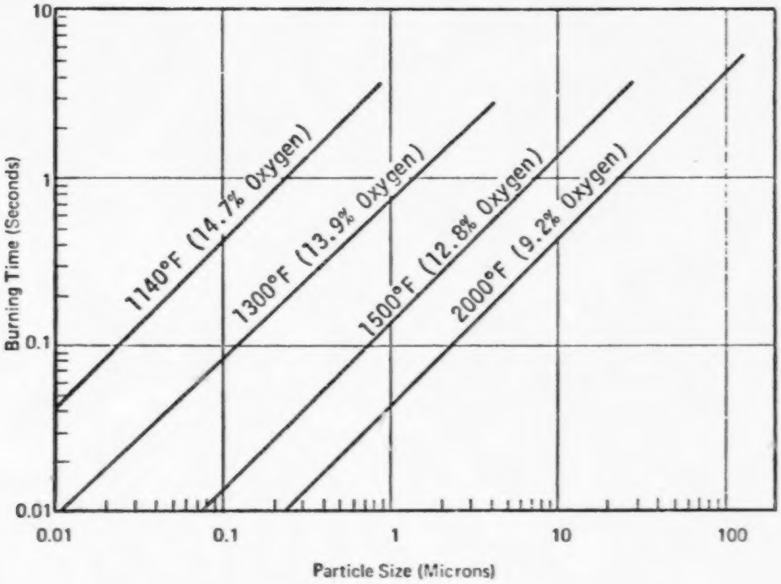


Figure 5: Times Required for Combustion of Carbonaceous Particles

TABLE 5
Assumed Nominal Concentrations of Gaseous Pollutants at Entrance to APC Device

Type	*Concentration ppm (volume)*	*Basis*
CO_2	45,000	ADL Estimated Average
CO	1,500	ADL Estimated Average
NO_2	15	Rose et al. JAPCA *8* (4), 297-309 (1959)
NO	35	Rose et al. JAPCA *8* (4), 297-309 (1959)
Total Hydrocarbons (as CH_4)	100	Recent Tests on 3 N.Y. City Area Incinerators
Total Organic Acids (as CH_3COOH)	1	Recent Tests on 3 N.Y. City Area Incinerators
Total Aldehydes (as HCHO)	3	Recent Tests on 3 N.Y. City Area Incinerators
SO_2	30	ADL Estimated Average
H_2SO_4	50	Recent Tests on 3 N.Y. City Area Incinerators
HCl	60	Recent Tests on 3 N.Y. City Area Incinerators
HF	< 1	Recent Tests on 3 N.Y. City Area Incinerators

If one considers a theoretical stage in which the liquid leaving is in equilibrium with the vapor leaving, the efficiency can be shown to be given by the equation:

$$\text{Control Efficiency} = 1 - \frac{P_{out}}{P_{in}} = \frac{LRT}{LRT+H} \quad (4)$$

where P_{out} and P_{in} are the partial pressures of the specific gas component in the outlet and inlet streams, respectively; L is the liquid flowrate in lb. mols of liquid per cubic foot of gas; R is the universal gas constant (0.7302 atmosphere ft.^{3}/lb. mol °R); T is the temperature in °R; and H is the Henry's Law constant in atmospheres/mol fraction. The computed maximum control values shown in Table 6 assume pure water as the scrub-

TABLE 6
Maximum Absorption Efficiency for Single Equilibrium Contact Stage*

Component	*Henry's Law Constant*		*Maximum Absorption Efficiency*	
	30°C(86°F)	*70°C(158°F)*	*30°C(86°F)*	*70°C(158°F)*
CO	6.2×10^4 atm/mol fract.	9.8×10^4 atm/mol fract.	0.003%	0.002%
NO	3.1×10^4	4.4×10^4	0.006	0.005
CH_4	3.0×10^4	1.0×10^5	0.006	0.002
CO_2	1.8×10^3	3.9×10^3	0.10	0.05
SO_2	1.6×10^1	1.3×10[illegible]	10.30	1.60
HCHO (formadelhyde)	1.2×10^1	1.4×10^2	13.30	1.50
CH_3COOH (acetic acid)	2.7×10^{-2}	1.8×10^{-1}	99.00	92.00
HF	3.0×10^{-3}	5.5×10^{-2}	100.00	97.00
HCl	2.0×10^{-5}	1.3×10^{-3}	100.00	100.00

*Assuming only trace quantities being absorbed in water, and using 10 gal per 1000 cubic feet of gas.

bing fluid. Higher removal efficiencies would be obtained, in general, for the acidic components if pH control is exercised. In any incinerator installations, however, the scrubber water is quite acidic such that lower removal efficiencies could be expected.

In practice, most concurrent flow scrubbers operate at an efficiency somewhat less than one theoretical stage. Wetted baffles, for example, should not be expected to attain more than two-tenths to three-tenths of a theoretical stage, while high-energy venturi scrubbers could closely approach one theoretical stage in efficiency. Most systems utilizing sprays would range between one-tenth and six-tenths of a theoretical stage. Counter-current flow, multiple tray plate-type scrubbers would exceed a theoretical stage in effectiveness. It should be noted, however, that, in general, the devices used for air pollution control on incinerators are designed for the removal of particulates rather than gaseous species. In many existing plants, considerable optimization could be effected if gaseous pollutant control were identified as an important objective. Indeed, based on forecast increases in HCl emission factor for municipal refuse incineration, it may become necessary to install wet scrubbers in municipal incinerators for gaseous pollutant recovery following particulate removal using devices such as electrostatic precipitators. In industrial applications, emphasis on good gas contacting efficiency, the use of multiple-countercurrent stages, and scrubber waste treatment should be strongly considered when significant quantities of pollutant gases, such as hydrogen chloride or sulfur oxides, may be emitted

Incinerator APC Economics

Incinerator APC system costs are of increasing importance in estimating plant economics. In large municipal incinerators, however, APC system investment or operating costs represents less than 10% of the corresponding costs for the entire plant. Indeed, the difference between high performance and low performance air pollution control in this application represents a change of only about 6% on the overall plant operating costs (including fixed costs). This can be seen in Figure 6 where the total operating cost in thousands of dollars per year is plotted against the particulate control efficiency for various APC systems in municipal incinerator applications. Of particular note is the fact that high pressure drop scrubbers are often the most expensive; much improved particulate efficiency can be obtained at lower cost with precipitators or bag filters in this example. It should be emphasized, however, that these calculations were prepared using a number of important assumptions concerning investment write-off, plant location, and the unit costs for plant labor and utilities, and in the context of the assumed normal effluent particulate composition shown as U.S.A. No. 2 in Figure 4. For a more comprehensive treatment of costs, the reader is referred to Reference 10.

SUMMARY

The emission rate of incineration systems has been shown to be strongly related to system design, operating practices, and waste composition. From the relationships between these parameters and emissions, estimates can be made to aid in the selection of control equipment. Also, these relationships suggest means to reduce the emission at the furnace outlet, thus minimizing the demands placed upon the APC equipment. It is seen, in addition, that APC systems should be selected in the context of a specific waste and incineration system.

ACKNOWLEDGEMENT

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REFERENCES

1. Eberhardt, H. and W. Mayer. "Experiences with Refuse Incinerators in Europe," *Proc. of 1968 National Incinerator Conference*, ASME, New York, pp. 142-53.

2. Stenburg, R. L., R. R. Horsley, R. A. Herrick, and A. H. Rose, Jr. "Effects of Design and Fuel Moisture on Incinerator Effluents," *Journal of A.P.C.A.*, *10* (1966) pp. 114-20.

3. Stenburg, R. L., R. P. Hangebrauck, D. J. Von Lehmden, and A. H. Rose, Jr. "Effects of High Volatile Fuel on Incinerator Effluents," *Journal of A.P.C.A.*, *11* (1961), pp. 376-83.

4. Smith, W. S. and E. W. Gruber. *Atmospheric Emissions from Coal Combustion - An Inventory Guide*, P.H.S. Pub. No. 999-AP-24, 1966.

5. Walker, A. B. and F. W. Schmitz. "Characteristics of Furnace Emissions From Large, Mechanically Stoked Municipal Incinerators," *Proceedings of 1964 National Incinerator Conference*, ASME, New York, pp. 64-73.

6 Stenburg, R. L., R. P. Hangebrauck, D. J. Von Lehmden, and A. H. Rose, Jr. "Field Evaluation of Combustion Air Effects on Atmospheric Emission From Municipal Incinerators," *Journal of A.P.C.A.*, *12* (1962) pp. 83-9.

7. Wright, F. J. *Twelfth Symposium (International) on Combustion*, Combustion Institute, 1969, pp. 867-75.

8. Engdahl, R. B. and W. S. Major. "Application of Overfire Jets to Prevent Smoke from Stationary Plants," Bituminous Coal Research, Inc., Tech. Paper No. VII, 1957.

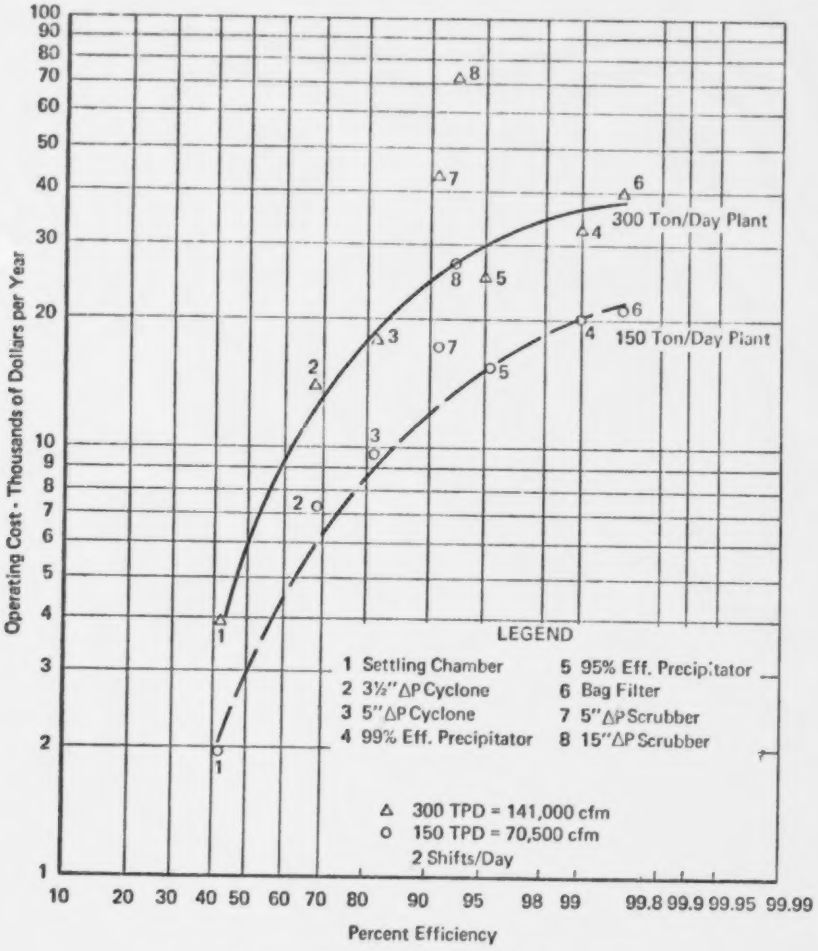

Figure 6: Total Annual Operating Cost vs. Particulate Removal Efficiency

9. Field, M. A., D. W. Gill, B. B. Morgan, and P. G. W. Hawksley. *Combustion of Pulverized Coal*, The British Coal Utilization Research Assn., 1967.

10. Niessen, W. R. "Systems Study of Air Pollution from Municipal Incineration," Report to NAPCA under Contract CPA 22-69-23 by Arthur D. Little, Inc., 1970.

11. Smith, W. S. *Atmospheric Emissions from Fuel Oil Combustion - An Inventory Guide*, P.H.S. Pub. No. 999-AP-2, 1962.

12. Longwell, J. P. and M. A. Weiss. *Ind. Eng. Chem.*, *47*, 1634 (1955).

13. Hottel, H. C., G. C. Williams, M. N. Nerheim, and G. R. Schneider, *Tenth Symposium (Internat'l) on Combustion*, The Combustion Institute, 1965, pp. 111.

14. Williams, G. C., H. C. Hottel, and A. C. Morgan. *Twelfth Symposium (Internat'l) on Combustion*, The Combustion Institute, 1969, pp. 913-25.

15. Mayer, A. R. "Untersuchung Über Zweitluftführ in Wandercostfeurungen," *Feuerungstecknik*, 26 (1938) pp. 201-10.

16. Woodruff, P. H. and G. P. Larson. "Combustion Profile of a Grate-Rotary Kiln Incinerator," *Proceedings of 1968 National Incinerator Conference*, ASME, New York, 1968, pp. 327-36.

17. Weintraub, M. A., Orning, A., and C. H. Schwartz. "Experimental Studies of Incineration in a Cylindrical Combustion Chamber," Bureau of Mines, RI 6908, 1967.

18. Shaw, J. T. and A. C. Thomas. *International Conference on Coal Science*, Prague, June 10-14, 1968.

19. Woolrich, P. F. *American Ind. Hyg. Assn., J.*, *22* (1961) pp. 481-84.

20. Kaiser, E. R. "The Sulfur Balance of Incinerators," *J. Air Pollution Control Assn.*, *18*, 3 (1968) pp. 171-4.

21. Andritzky, M. "Construction and Tests of the Flue Gas

Dust-Removal Unit in the Munich Incinerator Plant North I," *Brennst.-Warme-Kraft*, 19, 9 (1967) pp. 436-9.

22. Rampacek, C. "Reclaiming and Recycling Metals and Minerals Found in Municipal Incinerator Residues," *Proceedings of Symposium Mineral Waste Utilization*, March 27-8, 1968, pp. 124-31.

23. Hangebrauck, R. P., D. J. Von Lehmden, and J. E. Meeker. *Sources of Polynuclear Hydrocarbons in the Atmosphere*, U. S. Dept. of H.E.W., P.H.S., Cincinnati, Ohio (1967).

Theory of Fluidized Bed Incineration

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INTRODUCTION

The chemical industry has found that the fluidized bed offers economic advantages for many chemical reactions of the type

$$aA(\text{solid}) + bB(\text{gas}) \rightleftharpoons rR(\text{gas}) + sS(\text{solid}) + \text{Heat}^{1}$$

where it is important to obtain good contact between a reacting gas B and a solid reactant. This is the general type of reaction that takes place in solid waste incineration. Some understanding of its desirable characteristics is necessary before it is possible to make a valued judgement of the potential of a fluidized bed for solid waste incineration. It would appear appropriate that persons responsible for incineration should understand what makes the fluidized bed attractive to the chemical industry.

The purpose of this paper is the following:

(a) to describe the general characteristics of the fluidized bed for those who are unfamiliar with them;

(b) to describe how the fluidized bed can be used as a solid waste incinerator; and

(c) to discuss some of the major advantages and limitations of the fluidized bed.

General Description of the Fluidized Bed

The description undertaken in this section is qualitative and presents a pictorial view, or a "mind's eye view," of the fluidized bed. This section does not consider the many details and mathematical relationships that would be used in the design of a fluidized bed. These are available in any one of several texts on the subject.[2]

To visualize a fluidized bed, consider a cylindrical tube containing a granular solid that is held on a porous plate. Below the porous plate is a gas plenum. The gas flow through the porous plate into the tube can be controlled to any desired rate. This is shown in Figure 1. At low flow-rates, the bed of granular solid remains in its original "packed" state, and the pressure drop across the bed increases with flowrate. The pressure drop is due to the friction between the solid particles and the gas flowing past the solid surface. The pressure will continue to increase until the pressure drop across the bed is equal to the downward force exerted by the solids resting on the porous plate. Neglecting the friction of the container walls, the pressure drop cannot exceed the pressure due to the weight of the solids. Either the granular solid will move out of the cylinder as a slug or the solids must rearrange themselves in order not to exceed this limiting pressure drop. In the case of a fluidized bed, the bed expands, increasing the free area for gas flow. This allows more gas to pass through the bed at the same pressure drop. If we observe the particles at this point, the particles are not fixed and are not in contact with each other. They are separated by a

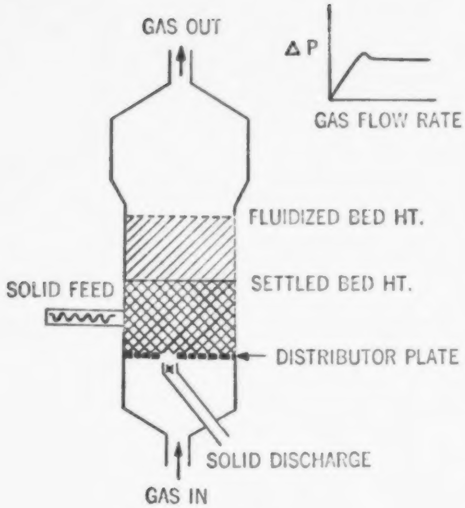

Figure 1: Fluidized Bed Reactor

thin layer of fluidizing gas. The particles do move, but the movement is small and constrained by their neighbors. This point is known as the point of incipient fluidization.

With a further increase in flowrate, the particles become free to move about, and the bed is fluidized. In this state, the bed has many characteristics of a fluid:

(a) It has an apparent viscosity;
(b) It obeys Archimedes' principle;
(c) It maintains a surface interface parallel to earth's surface; and
(d) It will flow from the cylindrical vessel.

As the flowrate is increased further, bubbles form in the bed and rise to the top. An analogy may be made to a rapidly boiling liquid. At high flowrates, this action becomes vigorous, and the particles in the bed are well mixed by the action of these bubbles; and it is this region of rapid particle agitation that holds the key to fluidized bed incineration. If the flowrate is increased still further, the terminal velocity of the particles is reached, and the particles are carried out of the vessel.

If one placed a heating surface at the top of the bed and a cooling surface at the bottom and measured the temperature gradient, one would obtain curves similar to Figure 2. For the case without gas flow, the temperature gradient will be straight and follows Fourier's Law. In the second case, before the point of incipient fluidization, some of the energy is being carried by the bulk flow of the gas. In the case where the bed is fluidized and agitated by the bubbles, no significant temperature gradient exists. Agitation of the bed particles transports energy from one region of the bed to the other. Using the liquid analogy once more, it can be observed that when a tall cylinder of liquid is placed on a heating element, a temperature gradient from the top to the bottom of the fluid will develop. To get a constant temperature throughout, the liquid is agitated and the bulk movement of the fluid results in one uniform liquid temperature. One method of agitation would be to bubble gas through the liquid. The same is true for a fluidized bed. Large heating or cooling surfaces may be placed in a fluidized bed, but the bed will remain, because of the rapid mixing of solids, essentially isothermal.

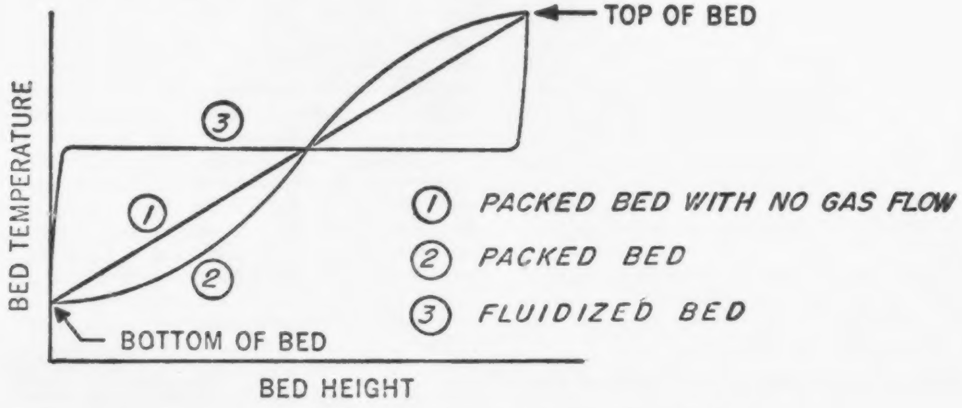

Figure 2: Temperature Profiles in Packed and Fluidized Beds

Before continuing to the description of the fluidized bed incinerator, one more analogy to liquids is made. It is possible to place your hand in an oven at 212°F for a long period without receiving a burn. However, placing your hand in boiling water at 212°F for a short time would result in a rapid reaction. The fluidized bed acts much like this boiling water; the rate of heat transfer is many times that of a gas stream at the same temperature.

The following characteristics of the fluidized bed have been deduced:

(1) Each particle is surrounded by a layer of the fluidizing media;
(2) The bed is at constant temperature;
(3) The rate of heat transfer in the bed is rapid; and
(4) The movement of solids is violent.

Description of a Fluidized Bed Incinerator

Returning to the original chemical reaction, equation 1, material A is the solid waste, B is the general oxygen in the air, R is the gaseous combustion products, and S is the solid residue. In order to initiate the reaction, it is necessary to heat the solid, A, up to an ignition temperature. Once ignited, the reaction gives off energy that must be removed. Figure 4 represents a bed of hot sand, at say 1800°F, that has been fluidized.

In the fluidized bed incinerator, the bed is made up of an inert solid, such as sand, and the fluidizing gas is air. The combustible material is introduced into the inert fluidized bed. The inert particle bed has two major functions:

(a) The fraction of combustible solids in the bed at any time is small (less than 1%). The size selected for the sand dictates the fluidization conditions and flow patterns for any gas flowrate. The vigorous agitation of this sand carries with it the combustible solids of a large size range. Small particles that would settle are directed and retained as part of the fluidized bed.

(b) The fluid bed acts as a thermal flywheel giving up and receiving energy from the combustible solids. If a heat transfer surface is inserted into the bed, it will remove energy and allow for more combustion to take place without the bed heating up. The fluidized bed is an efficient compact heat exchanger and, because of the high heat transfer rates, the amount of heat removal surface would be small.

The following series of events happens when a combustible solid is inserted into the bed:

(a) Because of high heat transfer rates, the particle rapidly heats up to its ignition temperature.

(b) Because the solid to be burned is surrounded by air, the gas (oxygen) quickly reacts with the combustible solid.

(c) The heat given off from the reaction is taken up by the bed. These steps are shown in Figure 3. If one had started out to describe a system that would be ideal for incineration, it would have included these characteristics.

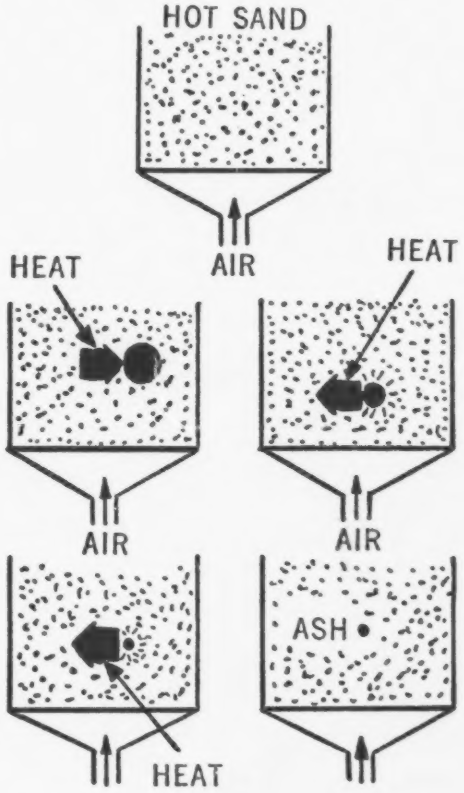

Figure 3: Combustion of Particle in Fluidized Bed

The fluidized bed has certain constraints that must be considered that limit the range of operation. Because the bed is made up of sand particles, the temperature of the bed cannot exceed a temperature in the range of 2,000°F so as not to approach the softening point. The gas flowrate at operating conditions cannot exceed the terminal velocity of the sand, nor can it be less than the minimum fluidization velocity. These velocities, as well as the heat transfer coefficients to the cooling

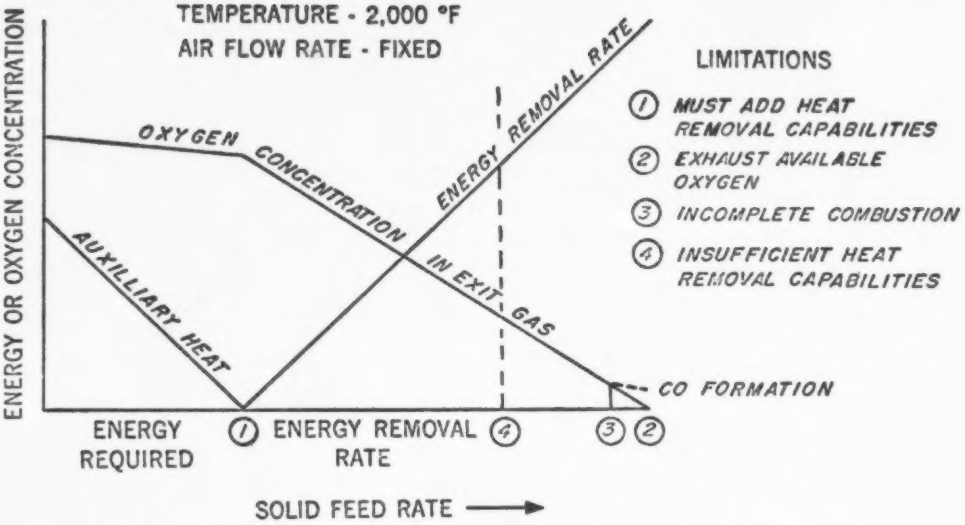

Figure 4: General Shape of Energy Requirements and Oxygen Concentration vs. Solid Feed Rate

surface, depend upon the particle size and the elutriation rate of combustible solids from the bed. It is obvious that the fluidized bed requires some form of size reduction before the combustible material may be fed to the bed. It can accept, however, quite a large range of particle sizes in the feed. The rather violent agitation of the sand bed helps to suspend large particles that would ordinarily be expected to find their way to the bottom. The fluidized bed retains these large particles for a sufficient time to allow them to burn.

Figure 4 represents the material and energy balance for a fluidized bed operating at 2,000°F and 5 times the minimum fluidization velocity for the given size sand. At a feed rate less than point 1 on this figure, an auxiliary energy source is required. At point 1 the bed is self-sustaining. If the feed rate were increased without removing energy, the maximum bed temperature would be exceeded. This limits the bed's capacity unless provisions are made for energy removal from the bed. Point 2 is the point where the oxygen supplied by the fluidizing air is consumed. If complete utilization of the air could be attained with complete combustion, this would be the limit of the feed rate. In this case, the removal of energy from the bed would result in an increase in capacity of about 300%. However, practical limits are less than this value. One limit, shown by point 4, could result if the necessary heat transfer surface could not be fit into the bed volume. The fluid bed has a high rate of heat transfer and the amount of heat transfer surface would be small. Another limit would occur when appreciable amounts of CO or other combustible gases are evolved. This is shown as point 3. Because of the good contact between the solid and gas, the combustion would be efficient and complete combustion would occur at low oxygen levels.

Because of the excellent heat transfer rates and the high contacting efficiency between the gas and the solid, the fluidized bed presents a system in which the generation of heat, steam, or electricity and efficient utilization of the combustion oxygen is possible. The reduced air requirements with energy removal result in smaller volume gas cleaning equipment to meet air pollution standards.

It has been found in the combustion of coal that solid additives that react with SO_2 and can be added to make up part of the bed. The SO_2 from the gas is retained with the solid. The potential exists for removing SO_2 and other gas pollutants from incinerator flue gas by the same technique.

Some Results of Investigations

Experiments have been carried out at West Virginia University on the combustion of many materials in a 15-inch diameter fluidized bed. A municipal refuse from Albuquerque, New Mexico, that had been shredded in a Eidel Shredder was fed to a fluidized bed. The experimental unit had no provision for heat removal. When operated at 1600°F, the following results were obtained:

(1) % unburned material	1.93%
(2) Heat release rate	228,000/ft.[2]
(3) Volume reduction	16/1

The unburned material left with the gas in the form of pyrolytic carbon.

A better appreciation of the effectiveness of a fluidized bed for combustion might be obtained by noting that a 3-inch diameter wooden log placed in the bed is consumed in 8-10 minutes. About the same time is required for ordinary hardwood charcoal briquettes used for barbeques.

Present Status

There are some cases where fluidized bed technology has been applied to solid gas reactions in the area of combustion of wastes. The most notable of these are the following:

(1) Dorr-Oliver: Fluo Solids unit for combustion of sewage sludge.[3]

(2) Copeland: Incineration black liquor from the paper industry.[1]

(3) Combustion Power Corporation: Generation of electricity from incineration of solids in a fluidized bed under pressure, followed by expansion through a turbine.

Only the Combustion Power Corporation Unit (CPU-400) will utilize common refuse as the energy source. Figure 5 shows the advanced concept incineration system being developed by Combustion Power Corporation. It is being developed under contract from the Bureau of Solid Waste Management.

The fluidized bed represents a process system that offers several advantages over conventional incineration. The process is not new and has found wide application in the chemical industry. In addition, consideration is being given in Britain for utilization of the fluidized bed in order to reduce the costs of electricity as

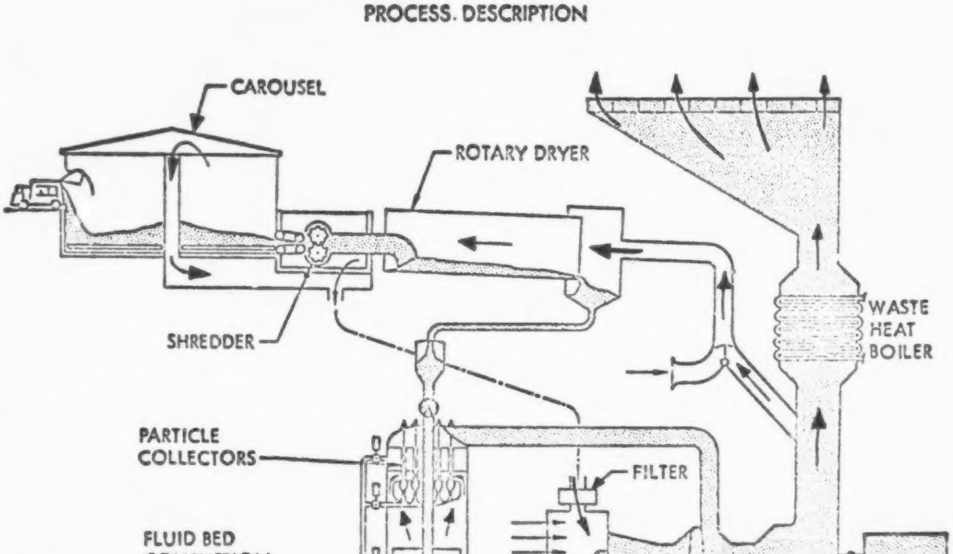

Figure 5: CPU-400 Solid Waste Disposal Process

well as the pollution resulting from coal-fired central power stations. The fluidized bed has not, however, been effectively utilized in the combustion of refuse. Programs supported by the Bureau of Solid Waste are being carried out to study solid waste incineration and gasification in a fluidized bed.

REFERENCES

1. Copeland, G. G. and J. E. Overall. *Pacific Coast Section Meeting PIMA*, Portland, Oregon, December 3, 1966.
2. Kunii, D. and O. Levenspiel. *Fluidization Engineering*, John Wiley and Sons (1969).
3. Millward, R. S. and W. A. Darby. *Water Waste Engineering*, Oct. 1967.

The Design and Operation of Fluidized Bed Incinerators for Solid and Liquid Wastes

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INTRODUCTION

In every country of the world, improving standards of living have been paralleled by increasing quantities of waste materials which sooner or later must be adequately disposed. The specter of this civilization drowning in a sea of waste of its own making is not entirely far-fetched.

In almost all waste material, carbon and hydrogen are present in varying quantities. This makes incineration or combustion one of the disposal processes which must be considered. While the conversion by combustion of carbon and hydrogen to carbon dioxide and water, respectively, may be considered a waste of elements, the release of these elements back to the atmosphere in a usable form may be more practical than allowing the unoxidized elements to rot in a pit or water course to no one's benefit.

Regardless of the philosophy of handling waste materials, incineration is being more and more widely used, and the fluidized bed technique has become an important modern tool in the process.

The so-called Copeland fluidized bed process was developed to incinerate a waste liquid from pulp and paper mills which could not be economically destroyed by any other process. As a result, there are eight pulp and paper mills in operation today which otherwise would have been out of business because of water pollution regulations. The process, a modification of simpler fluid bed systems, has been in commercial use for over ten years and is being applied successfully to disposal problems other than pulp and paper. These other commercial applications include wastes emanating from oil refineries, petrochemical plants, food manufacturers, the chemical industry, the distillery industry, municipal sewage sludge, and garbage. This paper deals with the design and operation of fluid bed incinerators as applied to industrial wastes.

Applications of Fluid Bed Incinerators

Fluid bed incinerators are finding application in the combustion of waste solids and liquids because in many cases these waste materials could not economically or practically be incinerated by older, more conventional equipment. The very fact that many waste solid materials have been used for landfill, rather than completely destroyed by combustion, is usually an indication of some difficulty being expected with conventional processes.

Since disposal usually implies an outright cost to the producer, the most efficient system must be found; and fluid beds are being chosen because of higher thermal efficiencies, better control of odors and particulate matter emissions, and a simpler process having greater design latitude.

Fluid bed incinerators have been demonstrated to be readily applicable to the combustion of the following types of solid waste materials:

(1) Domestic sewage sludge
(2) Municipal garbage
(3) Oil refinery wastes such as the following:
    (a) API separator sludge
    (b) Tank bottoms
    (c) Waste caustic streams
    (d) General refuse
(4) Petrochemical wastes such as the following:
    (a) Hydrocarbon compound sludges
    (b) Complexed waste inorganics
(5) Water treatment plant carbonate sludges
(6) Packing house wastes
(7) Distillery slop and materials not saleable as fodder
(8) Steel mill effluent clarifier sludges
(9) Bark, sawdust, and clarifier effluents from the pulp and paper industry
(10) The destruction of lethally poisonous materials.

The foregoing list is by no means complete, and it will be seen that some waste materials listed could be destroyed by combustion in older techniques. However, the high thermal efficiency of fluid beds makes it possible to incinerate these materials at much higher water contents without the use of extraneous fuel, thus giving fluid bed incinerators the nickname "Water Burners."

Design Considerations I, About Fluid Beds Generally

The principle of fluidizing solid materials at elevated temperatures in the presence of — and by means of — a gas was first commercially developed by the oil refining industry in the form of fluid bed catalytic crackers. While fluid bed incinerators only vaguely resemble "cat crackers," they do function because solid particles are set in fluid motion (fluidized) in an enclosed space (fluid bed zone) by passing combustion air through the fluid bed zone in such a way as to set all particles in that zone in a homogeneous boiling motion.

In this state, the particles are separated from each other by an envelope of the fluidizing gas (air for combustion) and thereby present an extended surface for a gas to solid reaction as, for example, air to carbon-hydrogen. It is this extended combustion surface that makes possible the high thermal efficiency found in most fluid bed reactors. Capacity is, therefore, a function of reactor bed total area but is usually expressed as fluid bed surface area.

At combustion equilibrium, the fluid bed resembles a boiling liquid and, in fact, obeys most of the hydraulic laws. The dispersion of fluidizing gas throughout the fluid bed zone by the specially designed orifice plate assures complete mixing, and temperature variations from any one spot in the fluid bed to any other will not normally exceed 10° to 15°F.

It is fundamental to any incineration process that there be no air pollution problem resulting from combustion of waste solids. In this respect, fluid bed units are generally superior to any other type of combustion. Again, this is due to the extended surface presented by the fluid bed medium. Copeland designed units which will normally burn 300,000 BTU's per square foot of grate area per hour. This could be compared, for example, with coal burning boilers which will do well to consume 40,000 BTU's per square foot of grate area per hour.

Copeland has a system in operation which has a 20-foot diameter bed which normally operates at five feet of depth. Total weight of the fluid bed is about 90 tons, but the surface area presented by the bed for combustion purposes is equivalent to a highway 70 feet wide by 69 miles in length. The unit burns waste liquors containing 62 percent water at a total heat release of 110,000,000 BTU's per hour, all without any extraneous fuel.

A commercial unit burning sewage sludge at 1400°F had the following stack gas analyses:

Mass Spectrographic Analyses

Sample	Component[2]								
	Volumes, Percent				*Parts Per Million*[3]				
Number[1]	CO_2	*A*	O_2	N_2	SO_2	COS	H_2S	NO_x	Hydrocarbon
1	5.17	0.73	14.4	79.7	N.D.	N.D.	N.D.	N.D.	N.D.
2	8.33	0.07	9.2	81.8	"	"	"	"	"
3	8.86	0.60	7.4	83.0	"	"	"	"	"

[1] Dry basis.
[2] Samples were taken at 11:30 a.m., October 30, 1968.
[3] N.D. means non-detected by mass spectrographic analyses.

Every installation built in the last ten years is meeting the air pollution regulations of the state in which it is located, and in fact, complies with the most stringent air pollution regulations of the country. This applies to both gaseous and particulate matter in exhaust gases.

The mass of fluid bed medium is kept at combustion temperature by oxidation of the organic material in the feed by the oxygen contained in the fluidizing air. There is little or no flame, but rather a flowing condition. Combustion is virtually instantaneous, and the fluid bed proper will contain no unburned organic material. Complete oxidation is the key to the control of air pollution.

In general, there will be a temperature difference between the freeboard or disengaging zone temperature and the fluid bed temperature. This is a function of many variables, but waste solids containing high water contents will get enough heat exchange (and evaporation of water) to give a 150°-300°F temperature differential. Conversely, waste materials with dissolved combustible gases or low boiling point liquids contained in the feed stream will give a reverse condition due to flashing in the freeboard.

A fluid bed at combustion temperature is a massive heat sink which levels out the impact of sudden feed changes or variations in fuel value. The fly-wheel effect of this heat sink is particularly important in the incineration of low fuel value waste materials which can cause "flame-outs" in older types of combustion equipment.

Perhaps the most important and least understood feature of Copeland incinerators is the ability to pelletize most inorganic ash residues to form the fluid bed medium itself. Many fluid bed incinerators use sized sand as the fluid bed medium, but the presence of low melting point inorganics makes pelletization a useful technique which, in some cases, permits the recovery of a saleable product uncontaminated by sand or other diluents. Pelletized ash is dust free and easy to handle. For this reason, where possible, we endeavor to force pellet growth in our incinerator systems.

In every case of forced pelletization, we find reduced dust collection problems and a generally easier operation. Pellet growth is a function of temperature and surface area in the bed itself, and its rate is controlled by controlling both temperature and unit area in the bed. By occasional screen analysis on the bed product, we can predict rate of growth and adjust it to the needs of the system.

Fluid bed system capacities are a function of superficial space velocity or the rate at which the fluidizing gas is forced through the fluid bed. A unit designed for a two-foot-per-second space velocity will give 100 percent additional capacity, if enough air is forced through it to raise the velocity to four feet per second *provided* the velocity is not sufficient to elutriate the bed material out of the reactor. Space velocities are chosen to meet a given set of feed conditions and will generally be in the range of 1.0 to 3.0 feet per second. Installations have been built for other purposes where the velocity has exceeded 10 feet per second.

Of great importance in basic design is the opportunity to build into fluid bed systems a future capacity at minimal cost. By installing a false brick lining in the fluid bed zone at the time of original construction, square footage is provided for future use. For example, a project requiring a ten-foot diameter reactor can get 30 percent future capacity built in by adding a one-foot thick false lining for less than a 5 percent increase in present cost.

Design Considerations II, Fluid Bed Incineration Process

Fundamental to the design of any fluid bed unit is a clear understanding of the waste material to be processed. Fluid beds will not work on material either too coarse in size to be fluidized or having an ash content with a lower melting point than the temperature necessary for complete oxidation of the organic matter. In this latter case, fluid beds do not differ from the older type incinerators.

Generally, it can be said that fluid beds will burn anything that can be fed into them and fluidized. Solid wastes with a minimum of free surface water are generally blown into the reactor, whereas dryer materials can be fed by means of a sealing type screw conveyor. Semi-plastic sludges such as sewage sludge are fed by screw conveyor or, more simply, by a progressing cavity pump. Thermoplastic materials like grease are most readily fed by first being melted and then being pumped by centrifugal pumps.

Wherever possible in our design, we try to build into the system enough freeboard residence time to permit some heat exchange between the incoming wet feed and the outgoing combustion gases. Since these gases are generally wasted, evaporation of water from the incoming feed by direct heat exchange has the effect of improving thermal efficiency.

We are currently designing a fluid bed incinerator which will be fed several different materials by three different feeding devices, all at the same time and all under automatic control. Provision is also being made to supply auxiliary fuel in case a major heat value deficiency occurs.

Before designing any fluid bed system, we pay particular attention to the chemical composition of the material and look for trace elements which might have a fluxing or fusion point lowering effect on the ash content. We have found, for example, that a fluid bed burning organic material, the ash content of which is 100 percent sodium chloride, can be operated in excess of 1300°F without fusion problems; yet, another product of the same type having 1½ percent sodium chloride could not be burned in excess of 1150°F without complete fusion. Obviously, a typical eutectic problem, but critical in any incinerator design.

All waste materials to be incinerated are usually analyzed by a bomb calorimeter to determine heating value since this is used in all design calculations and actually determines the design necessary for maximum thermal efficiency. Having determined the character of the feed material, the temperature necessary for complete and instantaneous oxidation of the organic fraction is fixed. Consideration is then given to side reactions, such as dissociation of any inorganic salts contained in the feed. At the same time, a determination is made as to whether the ash content can be made to pelletize for easier handling or whether it will be carried out of the system as a dust.

Design Considerations III, the Fluid Bed Reactor

A fluid bed incineration system will normally consist of the following components: (See Figure 1).

(1) The fluid bed reactor is made up of the following:

- (a) A wind box or plenum chamber
- (b) A distributor or orifice plate
- (c) The fluid bed or combustion zone
- (d) The disengagement or freeboard zone

(2) Main air supply furnishing air for both fluidization and oxidation (combustion)

(3) A primary dust collection system

(4) A secondary dust collection system

(5) A feed and product discharge system

(6) Instrumentation to make the system automatic in operation.

A description of these components is as follows:

Fluid Bed Reactor

The reactor proper is a carbon steel tank lined with insulating and refractory brick to suit the conditions of incineration. The plenum chamber or wind box is provided to insure proper air distribution below the orifice plate. The orifice plate separates the wind box from the fluid bed zone (See Figure 1) and is constructed of high alloy metals or refractory. Fluidizing air is passed through this plate by orifices which allow the passage of air but restrict the backward flow of bed material into the wind box.

Orifice tubes are designed for pressure drops in the area of 0.5 psig to 3.0 psig and are spaced so as to give as complete dispersion as possible. Pressure drop plays a significant part in pellet growth, especially in systems where the ash fusion point is close to organic flash point. We have systems in operation where pressure drop is 3 psig and the orifice tube gas exit velocity exceeds 400 miles per hour.

The orifice plate supports the bed during power failure or intermittent operation and must be designed to take major swings in temperature (e.g. 150°F to 2000°F) without distortion or buckling. The fluid bed zone contains the fluidized medium—either inert material such as sand or pelletized ash obtained from the feed material. Bed depth is controlled to give the desired residence time for the incineration conditions and is measured generally by pressure differential using the same techniques as used in measuring liquids. Withdrawal rate from the bed is adjusted to the rate of deposition of ash in the bed so as to maintain some predetermined depth of the bed.

Above the fluid bed zone is the largest portion of the reactor; the disengagement or freeboard zone. Here, the exiting exhaust gas is brought in contact with the incoming feed which acts as a scrubbing medium and is generally cooled by heat exchange with water in the feed.

Because of the major increase in volume resulting from steam generated by water released from the feed, freeboard zones are increased in diameter to reduce the exit gas velocity and, thereby, allow particulate solids to disengage from the gases and fall back into the fluid bed zone. The combination of freeboard feed and expanded freeboard diameter has a great bearing on reduced dust collection problems.

Main Air Supply

Air for combustion is normally supplied by blowers designed for pressures from 3.5 psig to 8.0 psig, depending on the character of the incineration problem. All Copeland combustion systems are forced draft, and we have had no problems with gas leakage in any installation. Induced draft fans have never been considered necessary.

A preheater for start-up purposes is usually hooked into the main air supply. Under certain conditions, a secondary fuel source may be pro-

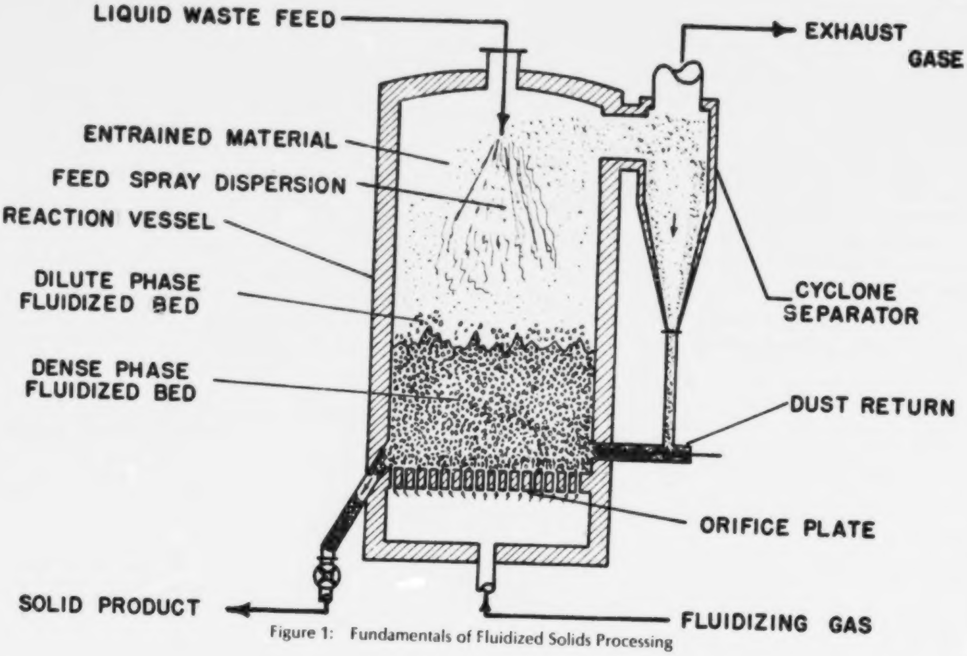

Figure 1: Fundamentals of Fluidized Solids Processing

vided to inject fuel directly into the fluid bed or alternately into the freeboard.

Primary Dust Collection System

The reactor exhaust gas from most incinerator installations will contain substantial particulate matter which must be moved from the gas. We normally use centrifugal cyclones designed for pressure drops of 8 to 15 inches of water. Early reactors used cyclones with much lower pressure drops, but air pollution regulations have forced our design to the higher levels. Aside from the higher energy required to push gas through the cyclones, we have found the higher pressure drop to be beneficial in handling some types of dust which have very low bulk densities (e.g. 5 to 10 pounds per cubic foot in the hot condition). The higher pressure drops also impose an increased velocity pressure which forces the separated low density materials out of the cyclone collectors.

Secondary Dust Collection or Gas Scrubbing System

Secondary collection or wet scrubbing has gone through a major change in the last five years because of air pollution regulations. Copeland systems are designed to control particulate emissions below 0.1 grains per standard cubic foot. This can only be achieved with high energy venturi scrubbers with specially designed mist and plume eliminators.

Wherever possible, liquid from the waste separation process preceding the incinerator is used as scrubbing medium. Pressure drops across high efficiency scrubbers run between 25 and 45 inches of water. Drops of this order are necessary to knock out 5 micron particles which otherwise would show in the stack gas as a plume which persists for miles.

Feed and Product Discharge System

Reactor feed systems are as varied as the incineration problem. About every conceivable type of feeding device known is in use today. In general, it might be said that the fluid bed incinerator can handle anything that can be fed to it, so the problem of feed preparation is a point of major design consideration.

Product is removed from the fluid bed zone by sealing devices which normally discharge to screw conveyors leading to storage for ultimate disposal. In many incinerator systems, the quantities to be so disposed of amount to a few pounds per day. Others produce in excess of 100 tons per day and are handled accordingly. Some non-pelletizing systems recover all ash as a cyclone collector product which is discharged to a sealed container. In the foregoing cases, the seals required are to equalize the 1 to 2 psig pressure inside the reactor and cyclone.

Instrumentation

Fluid bed systems, being a modern development, lend themselves to complete instrumentation and virtually completely automatic operation. We have systems being operated from a distant point without operator attention at the site and being run only eight hours per day. We suspect the ultimate in instrumentation is up to the client's imagination and pocketbook.

A Fluid Bed Case Study, Oil Refinery Waste Sludge Incinerator

A recent highly successful Copeland "first time" fluid bed incinerator installation was brought on stream in late 1969. This unit handles oil refinery wastes of various descriptions. The following is a description and case history of the process.

Description of Process

Feed:

Feed to the incinerator consists of the following:

(a) Oily sludges containing up to 50 percent water and 5 percent solids, typically API separator sludge;
(b) Tank bottoms of various types from oily sediments to waxy cakes;
(c) Stable emulsions from processes and from slop recovery operations; and
(d) Spent caustic solutions, typically 2 to 8 percent caustic, rich in mercaptans and sulfides.

Feed Preparation:

A 1,000 barrel feed tank with heater and mixer receives liquid oily components directly. Solid

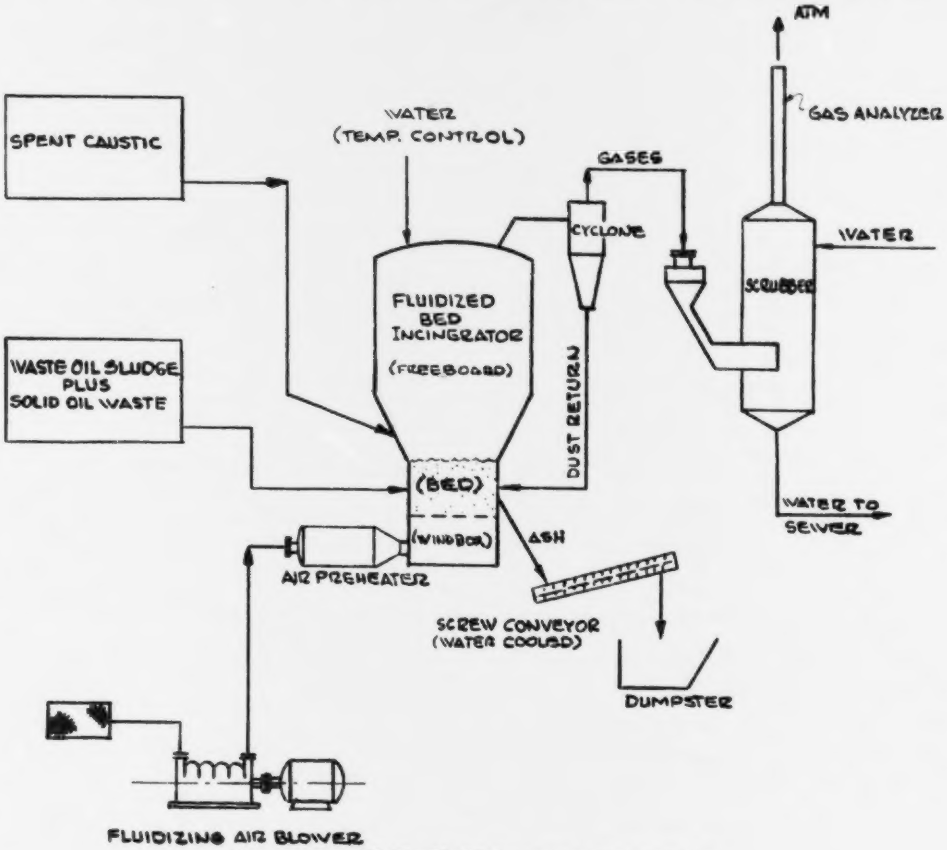
ATM
GAS ANALYZER
SPENT CAUSTIC
WATER (TEMP. CONTROL)
GASES
CYCLONE
WATER
SCRUBBER
FLUIDIZED BED INCINERATOR (FREEBOARD)
WASTE OIL SLUDGE PLUS SOLID OIL WASTE
DUST RETURN
(BED)
(WINDBOX)
ASH
WATER TO SEWER
AIR PREHEATER
SCREW CONVEYOR (WATER COOLED)
DUMPSTER
FLUIDIZING AIR BLOWER

Figure 2: Typical Fluidized-Bed Refinery Waste Incineration Unit

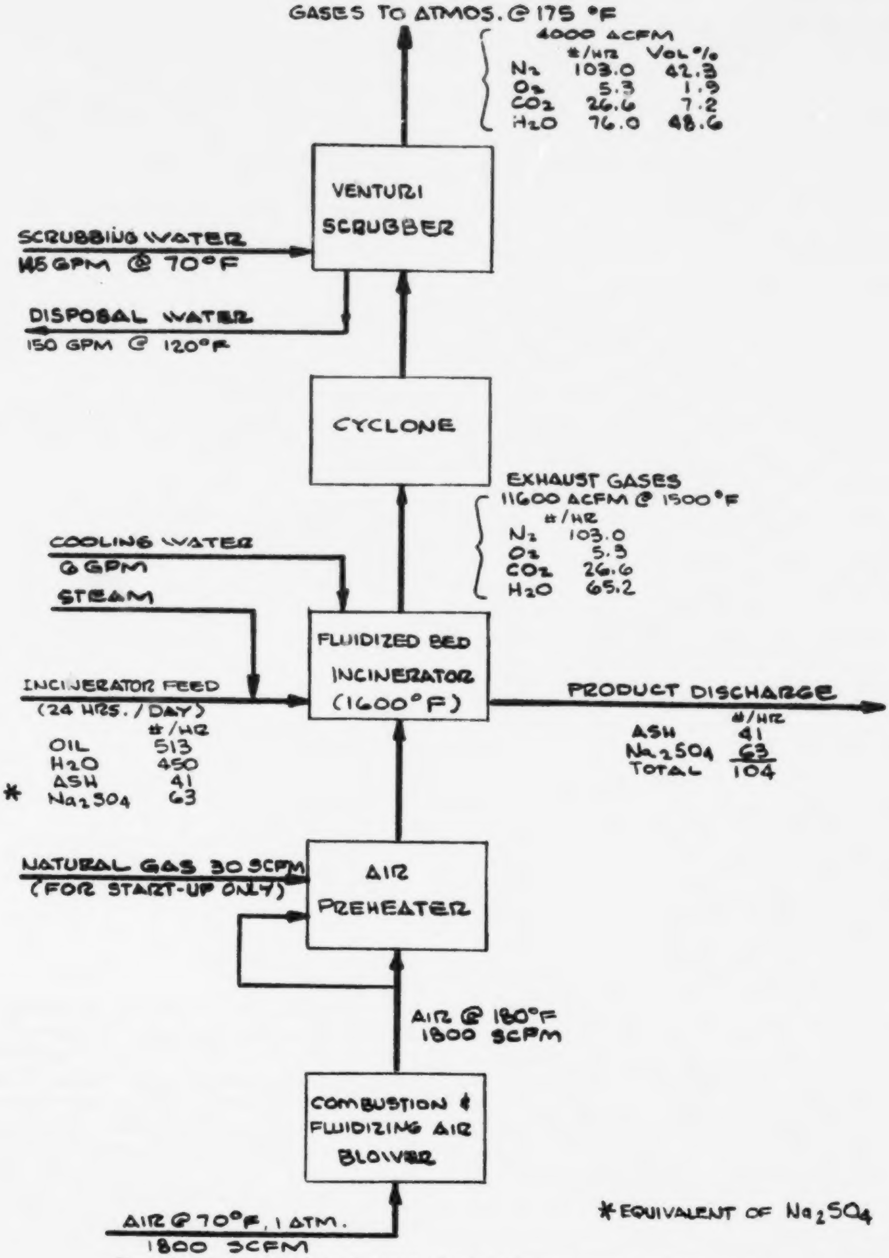
GASES TO ATMOS. @ 175 °F
4000 ACFM
#/HR VOL %
N2 103.0 42.3
O2 5.3 1.9
CO2 26.6 7.2
H2O 76.0 48.6
VENTURI SCRUBBER
SCRUBBING WATER 145 GPM @ 70°F
DISPOSAL WATER 150 GPM @ 120°F
CYCLONE
EXHAUST GASES
11600 ACFM @ 1500 °F
#/HR
N2 103.0
O2 5.3
CO2 26.6
H2O 65.2
COOLING WATER 6 GPM
STEAM
FLUIDIZED BED INCINERATOR (1600°F)
INCINERATOR FEED (24 HRS. / DAY)
#/HR
OIL 513
H2O 450
ASH 41
* Na2SO4 63
PRODUCT DISCHARGE
#/HR
ASH 41
Na2SO4 63
TOTAL 104
NATURAL GAS 30 SCFM (FOR START-UP ONLY)
AIR PREHEATER
AIR @ 180°F 1800 SCFM
COMBUSTION & FLUIDIZING AIR BLOWER
AIR @ 70°F, 1 ATM. 1800 SCFM
* EQUIVALENT OF Na2SO4

Figure 3: Material Balance for Typical Fluidized-Bed Refinery Waste Incineration Unit

sludges are dumped into a separate receiver, heated and mixed, then pumped to the oil feed tank. Caustic solutions are stored in a separate tank.

Incinerator Design:

The incinerator is a 12′ - 3″ OD × 27′ high internally insulated vessel containing about a four foot (static) bed of hot sand. A blower introduces air through this bed, causing fluidization and agitation. Oil feed is introduced near the bottom of the bed. Caustic is fed at the top of the bed. Effluent gases pass through a cyclone from which solids are returned to the bed, and off-gas goes to a scrubber. Scrubber water goes to the sewer, and cooled, scrubbed vapors go to atmosphere.

Operating Conditions:

The incinerator bed operates from 1200°F to 1500°F with about 4 to 6 percent oxygen in the effluent gases. Under these conditions and with caustic in the feed, carbonaceous materials are converted to carbon dioxide or solid carbonates; sulfur compounds are converted to sulfates. The carbonates and sulfates, together with any solid particulates in the feed, join the fluid bed and are drawn off as granules suitable for landfill. Off-gas consists only of carbon dioxide, oxygen, nitrogen, and water vapor, and appears as a dense white odorless plume during operation.

Figure 2 shows a sketch of the major parts of the fluid bed process. Figure 3 is a Material Balance Flowsheet across the system.

The plant management issued the following public statement at the dedication ceremonies in October of 1969:

> *Operating Experience* - The incinerator has been operating intermittently since August, 1969. The unit has proved relatively easy to start-up and, during operation, is manned only on a part-time basis by operators from an adjacent unit. Adequate safeguards are provided for alarm and remote shutdown in case of difficulties.
>
> After initial start-up mechanical problems were resolved, operation has been demonstrated to be practical, easily controllable, and effective in achieving the complete elimination of the refinery waste products. Problems remain in minor areas of operation, such as plugging of cooling sprays and control of operating conditions to minimize tendency of the bed to agglomerate.
>
> *Economics* - The key to economic disposal of the wastes for which this unit was designed is tailoring the flammable feed streams to permit incineration of the aqueous wastes without use of supplementary fuel. This requires some preplanning but has been achieved at the unit without much difficulty to date. The process becomes very expensive if the amount of caustic to be incinerated demands more heat than the available BTU content of the oily feeds. Utility requirements are primarily electricity to drive the blower, mixers and pumps, and cooling water for controlling temperature and for scrubbing effluent gases. Table 1 gives design data.
>
> *Feed (Design Basis)*
>
> Oily Sludges: 60 barrels per day of miscellaneous material containing 36 wt. % water and 5 wt. % solids.
>
> Spent Caustic: 10 barrels per day of caustic solution containing 7 wt. % sulfide sulfur and 1.2 wt. % mercaptan sulfur.

TABLE 1
Design Data

Utilities

1. Electrical	
440 v - 3φ - 60 cycle - KVA	142
110 v - 3φ - 60 cycle - KVA	10
2. Cooling Water, gpm	
53 psig@75°F	170
3. Natural Gas, scfm	
For start-up only	38
4. Steam, pounds per hour	
140 psig@430°F	790
5. Plant Air, scfm	
100 psig	35
6. Instrument Air, scfm	10
60 psig	

Start-up Experience

Due to the fact that most of the control instruments were remotely located several hundred feet away, we expected more than normal problems in the start-up and shake down of this unit. Walkie-talkies were employed to communicate between the incinerator site and the central control room, and only minor problems developed during the start-up period. In fact, with less than 10 days of start-up supervision by Copeland personnel, the client assumed operation of the system.

BSP Thermal Systems for Reclamation, Conversion and Incineration

G. F. KRONEBERGER

Following is an abstract of a film and slide series portraying high temperature thermal systems using BSP Multi-Hearth Furnaces and the low temperature wet conditioning BSP/Porteous Process.

The BSP Multi-Hearth Furnace, shown in cross section in Figure 1, is a high temperature (1000 to 2000°F) thermal processing unit which can process a variety of materials ranging from cast iron chips, granular materials, hogged wood, and shredded debris to fruit pits and nut shells. In these units, material is continuously fed in at the top, physically conducted through the multiple processing zones, and automatically discharged at the bottom. Processed residues can be captured and transported either mechanically in the dry state, hydraulically educted with water or other liquid media, or pneumatically conveyed.

Processed material is rabbled circumferentially and outward on an "out hearth," and at the periphery the material drops downward through the processing gases to the hearth below where the material is rabbled circumferentially and inward on an "in hearth" where it eventually drops through a center drop hole. A small pre-packaged furnace is shown in Figure 2.

Activated Carbon

BSP has been designing and building the "Pacific" Multiple Hearth Furnace for 50 years and is the world's largest manufacturer of this type of equipment (Figure 3). This unit is especially adapted for activated carbon regeneration and is the *only truly new* multiple hearth design available for this service.

The furnace is direct fired with carefully controlled burners. For further atmosphere control, a steam metering system can be provided to introduce live steam to the lower hearths for its beneficial effects on regeneration. As an alternate or addition, ducts can be furnished to recycle a portion of the flue gases.

The gases are updrafted counterflow and provide heat economically by drying and preheating the carbon on the upper hearths. Various off-gas control systems are available as appropriate to specific applications and plant locations.

Activated carbon has a variety of applications for selective adsorption in the process industries. In recent years its use has been increasing rapidly, largely because of the introduction of granular carbons. While the granular material is considerably more expensive than powdered

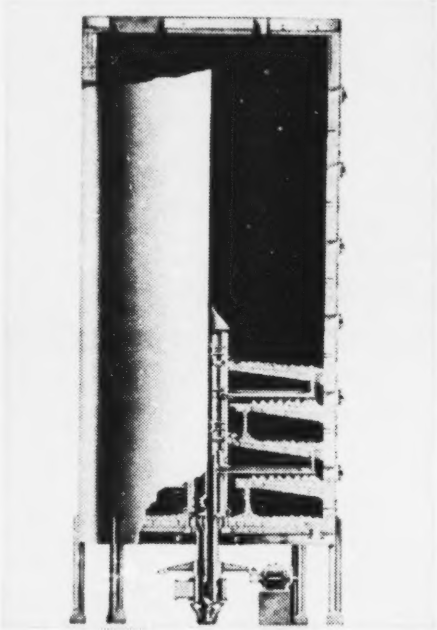

Figure 1: Cross-Section View of Furnace

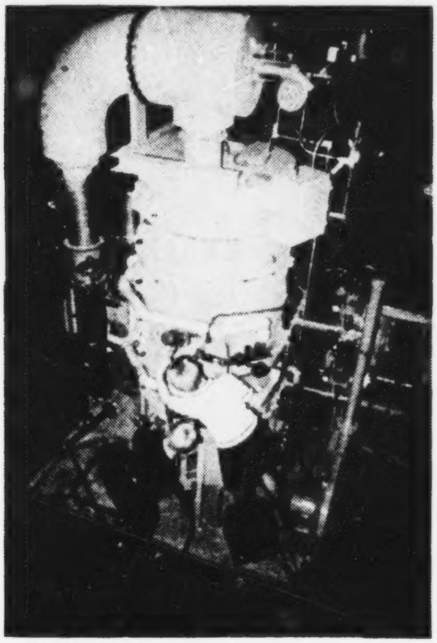

Figure 2: Small Pre-Packaged Furnace

carbons, it is more effective for many applications and *can be regenerated readily with losses of less than 5%* (Figure 4).

Since control of atmosphere and temperature determines losses and adsorptive quality, BSP engineers have concentrated their attention on these aspects. The result is a degree of control which sometimes produces a regenerated product more active than virgin carbon, always with the lowest possible losses.

In Figure 5, the hi-lighted circle shows the versatile BSP furnace. It is dwarfed by the drain-feed tank which is typically sized for the contents of a whole filter, though it can be smaller. The weather protected panel is shown on the right and in the background are five filters which can be connected in various combinations of parallel, series, and individual flow.

While the general design of the BSP equipment is standardized, each unit is specifically engineered to the customer's carbon installation. BSP is fully equipped for turnkey installations. Unit responsibility is accepted for design, engineering, manufacturing, erection, and start-up.

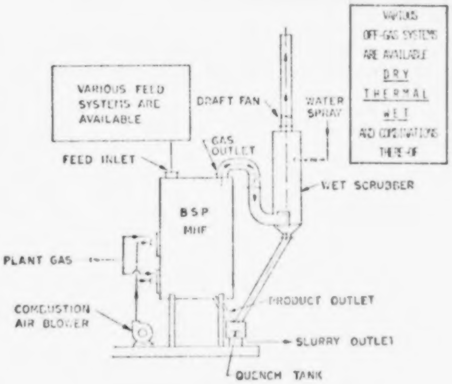
VARIOUS OFF-GAS SYSTEMS ARE AVAILABLE
DRY
THERMAL
WET
AND COMBINATIONS THERE-OF
VARIOUS FEED SYSTEMS ARE AVAILABLE
DRAFT FAN
WATER SPRAY
GAS OUTLET
FEED INLET
WET SCRUBBER
BSP MHF
PLANT GAS
COMBUSTION AIR BLOWER
PRODUCT OUTLET
SLURRY OUTLET
QUENCH TANK

Figure 3: Diagram of Basic BSP Process

BSP is the leading manufacturer of activated carbon regenerating equipment. This specialized experience assures that the equipment offered is the finest available.

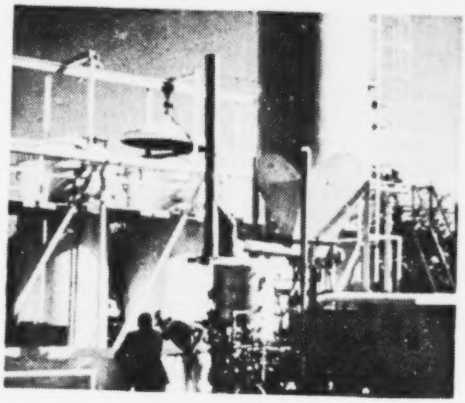

Figure 4

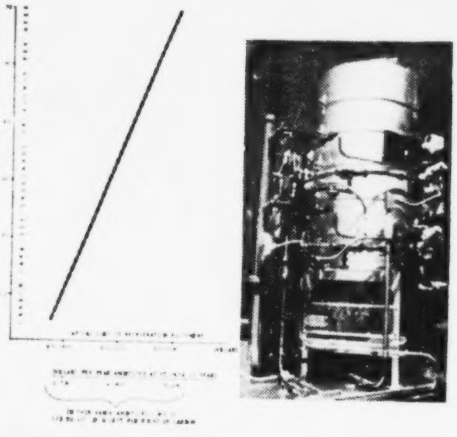

Figure 5

Charcoal

BSP Carbonizing Systems have been applied to a wide variety of materials ranging from wet wood wastes to semi-dry fruit and nut processing wastes (Figure 6). In all of these, the design of the equipment and process control is such that char can be produced to desired specifications despite varying feed characteristics. Systems have been installed with and without pre-drying systems, and BSP's newest concepts of internal heat reuse offer the advantages of high production without the extra equipment of external predryers, or the disadvantages of production limited unpowered off-gas systems. Heat recovery systems are available where desirable.

BSP Carbonizing Systems are high capacity units that are unmatched in performance and operating ease. Figure 7 shows conservative operating parameters, while the table shown in Figure 8 can be used to obtain the yield factor from known material characteristics.

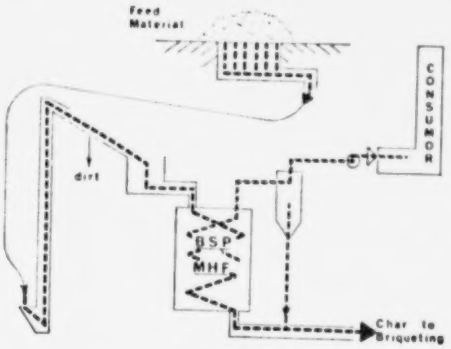

Figure 6: Char From Fruit Pits and Nut Shells

FEED COMPOSITION PERCENT: DRY SOLIDS	MOISTURE	OUTPUT FACTOR			
40	60	.08	.12	.16	.20
50	50	.10	.15	.20	.25
60	40	.12	.18	.24	.30
70	30	.14	.21	.28	.35
80	20	.16	.24	.32	.40
	DRY SOLIDS YIELD	.2	.3	.4	.5

Figure 7: Table to Determine Yield Factor from Known Material Characteristics

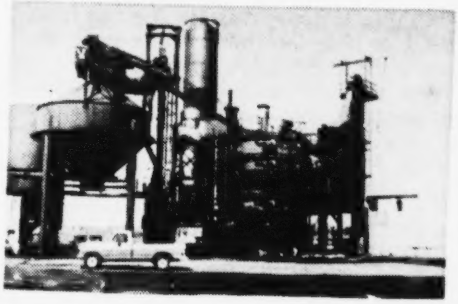

Figure 8

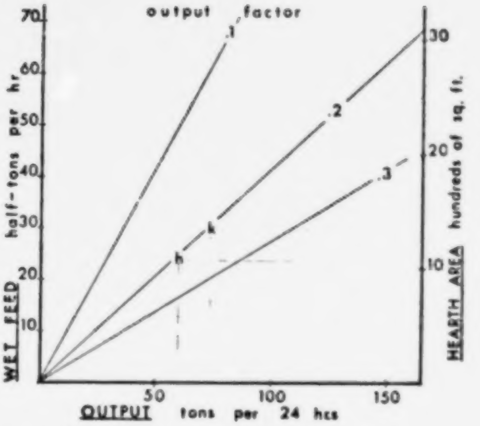

Figure 9: Conservative Operating Parameters

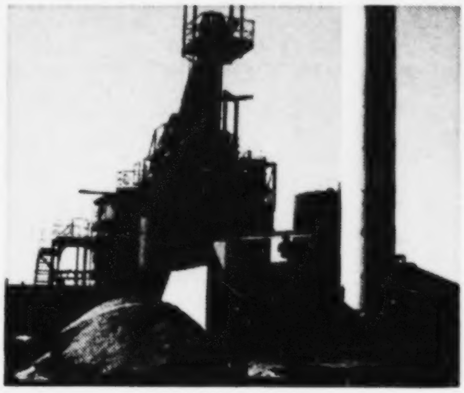

Figure 10

Lime

The simplified flow diagram of a lime facility (Figure 11) is very much like that of many other kinds of BSP Multiple Hearth installations. In all of these the optimized control, furnace design, and practical facility considerations are some of the main reasons for outstanding BSP performance. BSP installations are outstanding in being adaptable to changing plant requirements and operation. The fact that this same furnace concept can be applied to stone, mud, or precipitated lime means that the effect of normal changes in your own process are adapted to without crisis conditions. Overburning is a term inapplicable in BSP systems, as are shell build-up and misplaced chain sections.

In addition to adaptation to a wide variety of lime types, BSP Multiple Hearth Furnaces can be provided to suit any desired emphasis on capital vs. operating costs (Figure 12). While the feed composition (moisture, organics, CaO) sets the basic operating levels, it is possible to emphasize either production or operation economy; or, given free choice, our computerized calculations can choose the optimum design for a particular facility. Because of normal variations of cost keeping methods and the variations of costs from location to location, it is advisable to check costs directly before making facility decisions. In addition to furnace design variations, there are a selection of operating conditions that can be used to further optimize cost factors.

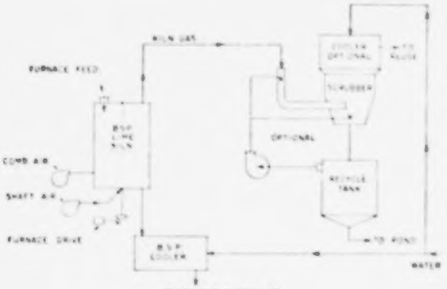
KILN GAS
FURNACE FEED
COOLER OPTIONAL
WITH REUSE
SCRUBBER
BSP LIME KILN
OPTIONAL
COMB AIR
SHAFT AIR
RECYCLE TANK
FURNACE DRIVE
BSP COOLER
TO POND
WATER
TO STORAGE SLAKING OR REUSE

Figure 11: Typical BSP Calcining System

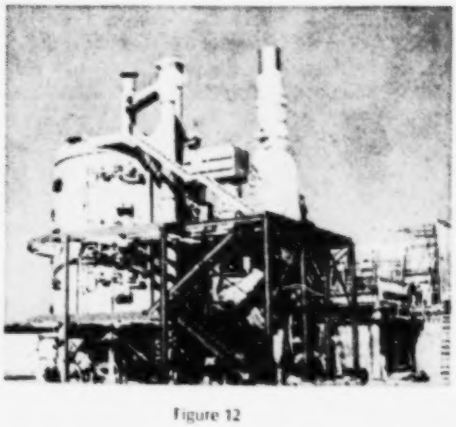

Figure 12

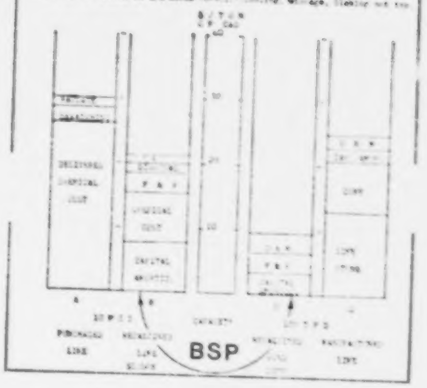

Figure 13: Cost Comparisons of Four Different Actual Operations

BSP Furnaces have been installed in both lime mud and air dried pond lime stone chips and have indicated high quality lime production. In all cases, conversion over 98% is obtainable. The installation in Figure 12 discharges over 100 tons per day of recalcined lime, and the furnace operation is not upset by normal fluctuations in organics, moisture or CaO content, and required furnace adaptation is either by automatic temperature control or by set-point change.

Metals, Incineration & Special Applications

The flow chart in Figure 14 shows a typical furnace installation. In addition to this updraft (counterflow) operation, special processes are benefitted by cross flow such as in mercury production, downdraft (parallel flow) as in high heat processes, and split flow, which offers the advantages of all three. Because of these features and others mentioned herein, BSP Multiple Hearth Furnaces have been installed in such diverse applications as gold ore roasting, manganese oxidation/reduction, activation, seawater-solids, uranium ore processing, grease and debris incineration, silver and sodium sulphate recovery, pulp and paper mill residue processing, and refinery purification processes.

Separate atmosphere control zones for the various stages of a process are just a portion of the outstanding features of BSP Multiple Hearth Furnaces. These and the equally controllable temperature zones compose a system that would be outstanding even without additional features. And there are additional features. For instance, the residence time for the process as a whole can be varied independently of the process air flows or requirements. And, with practical field changes, even the retention time in specific reaction zones can be increased or decreased. In the simplified chart shown in Figure 15, the predominant atmospheres are shown for various categories of processes; however, in a given process there can often be a complete range of atmospheres from controlled air starvation to controlled excess air.

The chart in Figure 18 shows the operating economies of the BSP MHF for wet solids incineration. Very few units can match the BSP MHF in processing materials auto-combustibly with heating values down to 3,000 BTU/lb as fed. If

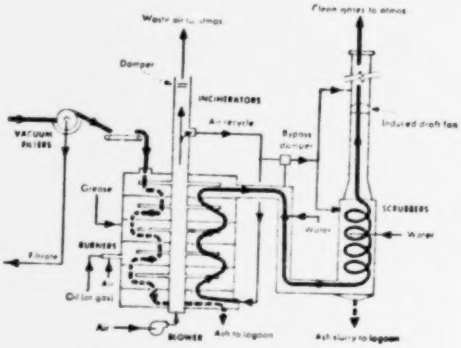

Figure 14: BSP Incineration System

Figure 15: 1000 PPH Unit

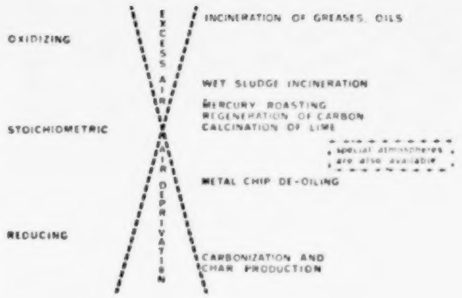
OXIDIZING
STOICHIOMETRIC
REDUCING
EXCESS AIR
AIR DEPRIVATION
INCINERATION OF GREASES, OILS
WET SLUDGE INCINERATION
MERCURY ROASTING
REGENERATION OF CARBON
CALCINATION OF LIME
special atmospheres are also available
METAL CHIP DE-OILING
CARBONIZATION AND CHAR PRODUCTION

Figure 16: BSP Furnaced (Apply to a Full Range of Processing Atmospheres)

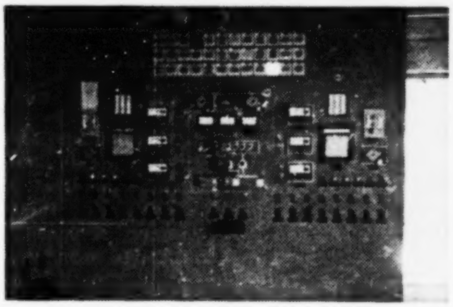

Figure 17: Dual Control Panel

the heating value is higher than required for self-sustaining combustion, the extra heat can be reclaimed from the off gases.

Because of zone conditioning, the unit is able to absorb variations without upset. Also, because there is no physical air requirement, the operating range is broad and relatively unaffected by heating value variations. For this same reason, particle sizes are normally unimportant and the system does not rely on pelletizing.

Porteous Process

The Porteous Process is a low temperature saturated steam pressure process for conditioning hard to dewater substances. This cyclic, thermo-basic process, through the use of modest amounts of heat, normally produces savings in chemical costs that equal or exceed cost of operation plus capital amortization as quickly as 3 years (see Figure 19).

In addition to making normally "hard to dewater" materials easy to dewater (and without

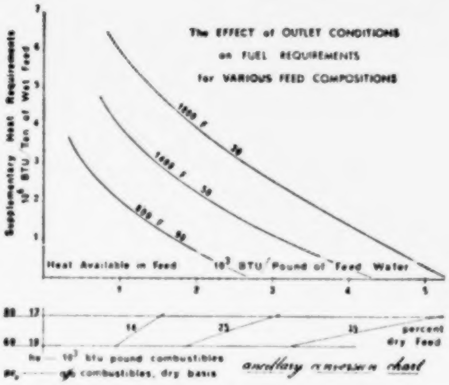

Figure 18: Additional Heat Required vs. Feed H. V.

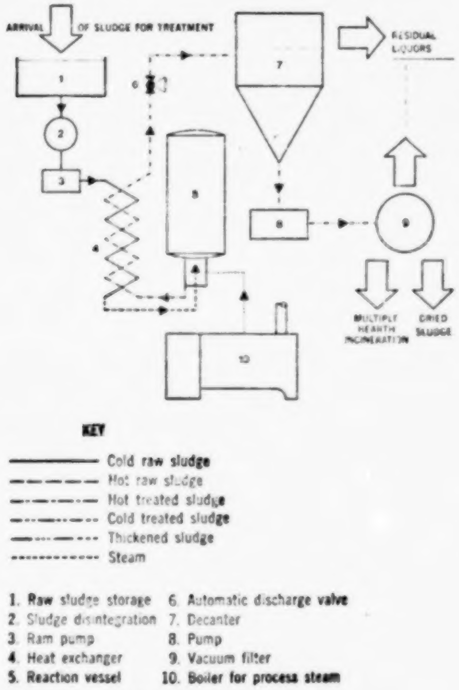
ARRIVAL OF SLUDGE FOR TREATMENT
RESIDUAL LIQUORS
1
2
3
4
5
6
7
8
9
10
MULTIPLE HEARTH INCINERATION
DRIED SLUDGE
KEY
Cold raw sludge
Hot raw sludge
Hot treated sludge
Cold treated sludge
Thickened sludge
Steam
1. Raw sludge storage
2. Sludge disintegration
3. Ram pump
4. Heat exchanger
5. Reaction vessel
6. Automatic discharge valve
7. Decanter
8. Pump
9. Vacuum filter
10. Boiler for process steam

Figure 19: Porteous Process

the use of chemicals), the Porteous Process produces a dewatered cake with a moisture content from 3 to 15 percentage units lower. In this way, even activated sludges can be dewatered to levels that heretofore were considered impractical. Porteous solids settle very well; however, this process can be followed by filtration and incineration.

Technological Advances in Secondary Fiber Usage

DR. A. T. LUEY
*Boxboard Research
and
Development Association*

The paper and paperboard industry is currently recovering and recycling about 20% of its products and the producers of combination paperboard depend almost entirely on waste paper for their basic raw material. The latest figures for 1969 show that, of the 58½ million tons of paper and paperboard used in the United States, approximately 11½ million tons were recovered and recycled. Over 8 million tons of these waste papers were used in the production of combination paperboard. If we can overcome the technological problems involved in the collection, transportation, and removal of contaminants, the quantity of waste papers recycled could be doubled. Since many people are intimately involved in the collection and subsequent disposal of millions of tons of solid waste containing waste paper, the eventual reuse of greater quantities will, in part, be their responsibility.

There are three major steps in the economic reuse of waste papers. These are the following:

(1) Collection and transportation;
(2) Classification by grade; and
(3) Stock cleaning or contaminant removal.

Traditionally, the collection of waste papers has been centered upon relatively large sources of supply such as industrial generators. The principle exception to this has been the collection of old newspapers by Boy Scouts and charitable groups.

The general public is currently engaged in the collection and transportation of waste papers along with many other materials. Possibly there will be some special cases; however, it would appear that three major classifications of waste paper are available to the public. These are news, corrugated, and mixed, and the names are self-explanatory. Fortunately, these grades are readily identified and make up the bulk of waste papers reused or recycled in the paper and paperboard industry. Technically, there is no limit to their reuse; and, with the growing shortage of fibers, it is predicted that the demand for these materials will steadily increase.

From a practical point of view, the reuse of paper stock is limited by the costs of collection, transportation, and contaminant removal. Since the costs of collection and transportation of solid waste are already covered, if the waste papers can be segregated and if excessive contamination can be avoided, there will be a market for these waste papers. A major city that is doing this successfully is London, England, They are reclaiming over 250,000 tons a year and making a profit. Madison, Wisconsin, has successfully demonstrated the feasibility of collecting news and is expanding its operations.

They are forced to collect and transport the material. By adding the steps of classification and avoiding excessive contamination, they have a saleable product. These additional steps pose a problem of material handling for which there is no generally accepted solution. In London they have fastened trailers to the rear of their compactors and accumulate the waste paper in these. In Madison, they have mounted wire baskets on their compactors to hold the news.

We believe that more satisfactory collection equipment could be developed if there were sufficient interest and demand by solid waste collectors. The Boxboard Research and Development Association would be willing to cooperate in the development of such equipment.

Although we speak of waste paper or paper stock, our interest is in the cellulose fibers that are the basic component of paper. The important point for this discussion is that these fibers can be reused countless times. Paper made from reused fibers is every bit as good, and in some aspects superior to the so-called virgin fiber sheet. Our problems in reusing these fibers is due entirely to the non-fibrous materials or contaminants that are invariably present.

Technically speaking, there is virtually no limit to stock cleaning or contaminant removal, and we can make the proverbial silk purse out of a sow's ear. Practically, or economically, we are limited by the quantity and type of contaminants present, and, therefore, a most important phase of this whole operation consists of preventing contamination at the start. Although our technology is changing rapidly, at the present time anything mixed with garbage becomes garbage, and we cannot use garbage to produce paperboard.

Odor will probably be an effective regulator or policeman of quality of waste papers recovered from solid waste. Everything has an odor and usually these odors are normal and acceptable. However, people who use paperboard for packaging a wide variety of materials are extremely sensitive to unusual or objectionable odors. As might be expected, the manufacturers of paperboard are equally as sensitive.

Since a general understanding of the composition and uses of combination paperboard is essential for an appreciation of the technological developments in its manufacture, this paper will deal with this briefly.

In the production of combination paperboard, as many as 7 or 8 layers of wet fibers will be continuously laminated to produce a thick sheet of paperboard. Each layer is made by an individual forming unit and is continuously transferred to a carrying belt or felt. The multiple layers of partially dewatered fibers are pressed to remove as much water as possible and then are passed over steam heated dryer cans. The drying operation will steam-sterilize the board.

By varying the composition and thickness of the individual plys, paperboard can be made with a wide range of physical qualities. In addition to the basic structure, clay coatings may be applied to the surface to enhance the appearance and printing qualities. Advances in the technology of clay coatings to achieve whiteness on combination paperboard has greatly reduced the consumption of bleached virgin pulps for these products. Formerly, 10% to 25% of the furnish of white lined grades was bleached virgin pulps, but these have been essentially eliminated today and waste paper is used 100%. Because combination paperboard consists of multiply plys, one can put the less expensive bulk grades of waste paper in the center or back side of the sheet and use the more expensive and whiter grades on the top. In contrast to this, paperboard made of a single ply, as is done on Fourdrinier machines using virgin bleached kraft, a high quality raw material must be used for the entire sheet.

Paperboard produced by the multiply process has a wide variety of uses ranging from the relatively inexpensive chip board found on the back of paper tablets to high quality cartons for packaging breakfast cereals, soaps, and cosmetics. High speed equipment used in the manufacture of these cartons place strict specifications on the quality and uniformity of the paperboard. Packaging lines operating above 100 units per minute demand quality and uniformity.

Technological developments in recent years have revolutionized the production of combination paperboard so that we are able to meet and exceed the specifications for various end-use requirements. The economic success of the total operation depends upon an adequate supply of waste paper with a reasonable degree of cleanliness.

As short a time as 25 years ago, most combination paperboard mills did not need to clean their paper stock. It was possible to purchase supplies of clean waste paper and one simply needed to defiber it in order to make paperboard. The only cleaning that did take place was incidental to a final screening just before the board machine which was done to remove any undefibered clumps of paper.

Today stock cleaning starts in the first stage of pulping. Continuous defibering or pulping machines will discharge material through 1/4" holes. The pulping is like a huge Waring Blender and heavy materials will be removed through an opening in the side, while pieces of cloth and rope will twine around a wire cable hanging over the side.

After the pulper, the stock will pass through a centrifugal cleaner of the liquid cyclone type. Next will be a screen with .087" holes. Then there will be more centrifugal cleaners operating at high velocities. The stock is given a final screening just before the machine in which it is passed through slots as fine as .014". Putting fibers over 1/2" long through slots that narrow is quite a technological accomplishment, but it is standard procedure today in many mills.

Everything that we are doing today to remove oversized and heavy materials could have been done 25 years ago but the equipment available at that time was so cumbersome and inefficient that it was simpler to avoid the problem by using clean waste papers.

Rifflers were used to remove heavy material. Diluted stock was fed slowly through a large, shallow container having submerged baffles. Heavy material was settled by simple gravity. The space requirements were large and the efficiency of contaminant removal was not very high. Today these have been replaced by liquid cyclones which have a high level of efficiency and require a modest amount of space.

Slotted screens have been available for many years, but they have been revolutionized in the past five years. Space requirements have been cut to a fraction of that previously needed, the width of the slots reduced 50%, and the equipment cost, even with today's inflated prices, is only slightly higher.

So far procedures for removing oversized or heavy particles have been mentioned. In addition to this, some contaminants are broken up into very fine pieces so that they are no longer objectionable. An example of this is asphalt which is frequently found in tapes used to seal corrugated cartons. In order to disperse asphalt, the stock will be dewatered, passed continuously through an enclosed, pressurized heating tube to melt the asphalt, and then agitated violently as it is discharged to the atmosphere.

By using techniques that have been briefly described, we are able to cope with most all types of contaminants. However, we are fighting a defensive battle. The polymer chemists are continuously creating new products that contaminate waste papers, and we are continuously developing methods of dealing with these new problems. At the present, our major concern is how to handle hot melts and pressure-sensitive adhesives, and we have a research program directed toward this specific problem.

In conclusion the following should be emphasized:

(1) There is a growing shortage of virgin fibers which will result in an increased demand for waste papers.

(2) One of the major costs in the reuse of waste paper is in its collection and transportation.

(3) Since the collection and transportation of solid waste results in the accumulation of a great quantity of waste paper, if it is separated from other refuse to avoid excessive contamination, it can be reused in the manufacture of combination paperboard.

(4) Finally, the Boxboard Research and Development Association is willing to cooperate in the development of any new method of salvaging waste papers.

Segregation and Classification of Waste Paper

HASKELL STOVROFF
Buffalo Paper Stock Company

The exact history of waste paper utilization in the manufacture of paper and paperboard in the United States is unknown. However, we do know that several companies have been engaged in the collection and processing of this material for nearly 100 years. The waste paper dealer, or as we now prefer to identify him, paper stock dealer, evolved from the old-fashioned dealer in all waste materials. Eventually, the dealers began to specialize in different commodities, although they were often collected by an individual collector who picked up metals, textiles, and iron, as well as paper.

The innumerable paper converting, printing, industrial, commercial, and other business establishments, as well as the households, all generate waste paper. They generate this waste paper as an incidental product of their daily operations and lives at the rate of 576 pounds per person per year. This material is the raw material for the paper stock industry which consists of collectors, packers, and dealers, whose principal functions are the collection, sorting, grading, packing, and consolidating of large tonnages of properly prepared paper stock to be used by the consuming industry.

Usage of waste paper as a raw material gained in importance around the turn of the century. First recorded consumption statistics were 556,000 tons in 1904, nearly doubling by 1910. By 1969, this recycling approached 11,000,000 tons, which is more tonnage than the annual total paper and paperboard production of any other country.

Just as there is a wide variety of types of paper and paperboard, so too is there a wide variety of types of waste paper which, after all, is simply paper and paperboard which has served its original purpose. Waste paper is a heterogeneous product. It consists of materials, ranging from the clean, white, unused envelope cuttings through business papers to a mixture of papers of varying cleanliness. Various items offer various fiber lengths and strengths. For example, the fiber in old corrugated containers offers necessary strength, while the short fibers in newspapers are used where strength is not the criteria.

The waste paper, after processing by the dealer, falls into three major categories of paper stock. The first and largest category is the "bulk grade" paper stock which consists of old newspapers, corrugated containers, and mixed papers. This category accounts for approximately 80% of all paper stock consumed in paper and paperboard mills. The bulk grades are used primarily for the manufacture of paperboard, construction paper, building board, and for products such as folding cartons, wallboards, roofing felt, moulded products, and many others.

The second major category of paper stock consists of direct pulp substitutes. These grades are typically generated as waste trim by mills and converting and printing plants. Envelope cuttings, manila tabulating cards, unprinted book and stationery papers, and corrugated box trim are examples of direct pulp substitutes. These grades do not have to be de-inked or treated before being used.

The third category is the de-inking grades. The new development of de-inking newspapers for newsprint will be covered by Mr. John Rich, President of Garden State Paper Company. Tissue and printing paper mills are using an increasing amount of printed and colored grades of paper stock. They remove the ink and pigment, thereby replacing the virgin pulp formerly used to manufacture these products.

In 1913, a group of dealers formed what was then called the National Association of Waste Material Dealers which has now grown and developed into the present National Association of Secondary Materials Industries, Inc. The Paper Stock Institute of America is a commodity division of this Association and operates autonomously within the framework of that organization. The Paper Stock Institute has standing committees for traffic, research and planning, liaison, production, and standards and practices, as well as special committees studying special projects at any time.

One of the most important projects of the Paper Stock Institute came as a result of recognizing the need for a uniform classification of grades of waste paper. This was done by a special committee of dealers and consuming mills working for two years from 1947 to 1949 to develop proper trade practices between buyers and sellers at every level in the industry, as well as to develop accepted descriptions of the grades most commonly traded in. These standards, specifications, and practices were published by the Paper Stock Institute in 1949 and referred to as PS-49. A standing committee has reviewed it periodically and revised it about every two years so that we now have a current document, PS-70 with which most people in the industry are familiar.

The grade descriptions referred to in PS-70 are to be used as a guide. This is not a mandatory document since paper stock, because of its very nature, does not lend itself to rigid specifications like materials which are mined or manufactured. The raw material from which paper stock grades are sorted and packed are generated by industry or are the by-products of converting or printing operations within the paper industry. In the case of the high grades, the availability of these items is limited by the business activity of the converters. In the case of the bulk grades, the availability is usually determined by the economic factors or price levels and the sustained demand by the consumers.

About 20% of all production is non-recoverable because it consists of items such as tissue, building boards, roofing material, etc. Since approximately 20 percent of the paper and board which is produced in the United States is recovered as secondary fiber, what happens to the remaining 60 percent? Obviously, it is either being incinerated or going into landfill.

The paper stock dealer is playing an important part in solid waste management and appears to be about to play a far more important role in the future. In the past, every large paper stock organization did extensive hand sorting of paper stock to create pulp substitutes which provided substantial savings to the mill users. In recent years, there has been a tremendous increase in pulp mills on the North American continent with the result that these pulp mills which were often affiliated with integrated paper and converting companies, made this virgin pulp available at very low prices. This naturally resulted in a price level for the pulp substitutes and other grades of paper stock which was so low that the paper stock dealers were forced to discontinue such operations and abandon the collection and packing of a great deal of valuable fiber, thereby creating additional problems of disposal.

Fortunately, the future looks bright for a correction of this condition. With the rising standard of living in the developing countries and the tremendous population increase in the United States, the pulp markets of the world have firmed considerably. There is a renewed interest in the use of secondary fiber on the part of former users as well as tremendous interest on the part of new users. Many companies are seriously studying and even building de-inking plants which can use the higher grades of paper stock instead of virgin pulp. This will result in more tonnage being diverted from solid waste to a satisfactory raw material.

Most of us in the industry see an increasing demand, and many dealers, including our own company, have installed modern automated handling and baling equipment and are developing relationships with the municipalities or private refuse haulers, encouraging them to separate the paper from other refuse, especially at points of substantial collection such as shopping centers and food market distribution centers. By making it attractive and providing revenue to the municipality or refuse hauler for clean corrugated cases and other paper to be delivered and dumped in a central city location without waiting, the dealer is making it possible to recycle this needed fiber rather than having it remain a disposal problem at a much higher cost.

We find many private refuse companies interested in installing two stationary compactors, one for corrugated cases and the other for all other refuse. By doing so, they can reduce the service charges to be paid by the generator, as the revenue derived from the paper and the saving in the vehicle time and transportation costs make this possible. Our own company, Buffalo Paper Stock Company, and its affiliated company, Consolidated Fibers, operates ten paper stock plants . . . a very large one in Buffalo, the remainder in California and Arizona. We experimented with a modern high density installation, one of the first in the industry, at Phoenix, Arizona, and are now completing the most sophisticated, automated system developed to date in our plant in Buffalo. This installation includes a twelve thousand square foot receiving building with a twenty-five foot ceiling to permit dumping inside, as well as a twenty-five thousand square foot paved area in front of the receiving building. The material is unloaded and pushed onto a 72-inch wide steel conveyor into a hogger or shredding machine powered by a 200 h.p. motor. It is discharged into a 28-inch duct by means of a materials handling fan driven by a 125 h.p. motor. Air conveys this material through a 240-inch diameter cyclone or collector which drops the shredded material into a continuously operating horizontal baler. This facility has a rated capacity of processing old corrugated boxes at the rate of 15 tons per hour and newspapers at the rate of 12 tons per hour. This is the type of equipment which is going to make it possible to recycle the bulk grades and convert them from being a disposal problem to a useful fiber in the paper industry.

In the future, we can expect to see revolutionary equipment enabling grades of waste paper to be separated right out of bulk refuse. Indicative of the research in this area is the laboratory-size, zig-zag air-classification unit set up at Stanford Research Institute in an assessment of the economic feasibility of air classification as a method of separating dry fractions of solid waste. Similar technology is under study at Franklin Research Institute as well.

Although the overall size of our industry is such that we cannot afford a full-time research and development staff, individually and collectively we are making every effort to investigate new equipment and techniques. Through our parent trade association, NASMI, we have committed ourselves toward assistance in better waste management.

The paper stock industry stands ready, willing, and able to collect and process far more tonnage than is now being done, if new uses can be found for such fiber. We recognize that we must assume a role of consultants to our cities burdened by solid waste disposal. We realize, too, the need for liaison with the private refuse haulers who control the destiny of the potentially valuable waste they collect. We appreciate the value of research necessary to improve our processing capabilities. In short, we are confident that the future includes far greater utilization of secondary fibers, which will be provided, in large part, by the paper stock industry.

Paper Manufacturing Technology for Processing Waste Paper

JOHN H. RICH
Garden State Paper Company

Last year, Americans threw more than 38 million tons of paper and paperboard into the garbage. The significance of this figure is that virtually all of it could have been recycled. Although a typical analysis of the composition and content of municipal refuse indicates that paper and paperboard products may range from 13.0 percent[1] to 58.6 percent,[2] we estimate that 41[3] to 42 percent[4] is a realistic national average. In other words, nearly one half of our cities' critical garbage volume has the potential to be reused.

While this conference will most likely result in offering new and improved methods and technology for the collection, processing, and disposal of solid wastes, there can be no doubt that a major outcome will be the emphasis placed on recycling of potentially valuable waste into productive use. In the paper industry, this is an old story because the utilization of waste paper as a raw material has a long history.

Adjusted for the import/export difference, this industry generated 58.5 million tons of paper and paperboard products on the national market last year. However, 8.6 million tons represented nonpackaging paper - items such as toilet paper, book covers, panel and gypsum board, and so on — paper that becomes liquid waste or no waste at all. This reduced the overall volume to contend with to 49.9 million tons, of which 11.4 million or 22.8 percent was reclaimed.

In other words, the paper industry recovered more than 11 million tons that otherwise would most certainly have been heaped on our dangerously overcrowded garbage dumps, and there are only three good reasons why the rest was not reused too:

First, the collection systems currently being employed across the nation are generally antiquated and inadequate for providing a reliable and economical supply of paper stock.

Second, but tied directly to the first reason, is the historic absence of a reliable demand by the paper and board industry for paper stock.

Third, efforts by our industry to produce extremely durable and versatile products have resulted in a major portion of the finished paper and paperboard being coated, impregnated, or laminated with clay, inks, wax, asphalt, additives, plastics, foils, and so on — all of which are considered contaminants when evaluating their repulpability.

It is encouraging to note what Dr. Luey[5] has written about the substantial gains of research and new hardware aimed at greater utilization of secondary fibers. But while scientific and engineering technology is continually addressing itself to the problems of contamination, there is not much point in holding our recycling as a potentially major breakthrough in the solid waste crisis unless we all do something about a reliable supply and a reliable demand.

Two weeks ago in San Francisco, Leo Cherne, Executive Director of the Research Institute of America, told the 57th Annual Convention of the National Association of Secondary Materials Industry, the industry that collects the glass, metals, and paper for reuse, that it had suddenly moved to center stage of not only the nation's preoccupation, but also of the *world's* preoccupation. He threw out the challenge to America's waste dealers to meet the critical demand of this nation for solid waste relief and conservation. Whether or not the dealer will be able to meet the challenge, under existing circumstances, is doubtful.

There are few people involved in the reuse of secondary fibers who have not heard a paper stock dealer relate the problems of staying in business, much less staying competitive, while taking on a public education campaign at the same time. Operating quite often on a limited margin of profit, left at the mercy of an unreliable labor force, plagued by weather - both hot and cold, - and constantly faced with the traditional indifference of the mill, he is nevertheless the keystone of today's secondary materials industry.

But it would appear to us, as a major consumer of newspaper, that the days of the door-to-door collection wagon are numbered, and that the number of people who are willing to man an upstroke baler is rapidly diminishing. After all, welfare payments often come so close to the wages that can be paid by a scrap dealer that there is little incentive for the laborer to take a job in a press. And when he does, the conditions and nature of the employment are such that it takes very little encouragement to get him to stay home on a cold or rainy day.

And who can blame him? It does not look as if his employer will ever be able to offer the laborer the type of advancement the manager of a paper mill can offer a bundle-handler or clerk. The only practical answer to the plight of the paper stock dealer is automation, but automation that is closely coupled with new and better ways to make paper available to him.

We can safely anticipate that within the next 10 years the number of paper stock dealers active in the country will be substantially reduced below the present number if for no other reason than because of attrition. This will mean that new and better ways to collect paper must be developed in order to meet the economical demands of the expensive automated equipment the dealer must install. To that end, we are supporting legislation that will compel the public to meet the crises of solid waste while simultaneously meeting the growing demands of the secondary materials industry.

With government cooperation on the national, state, and local levels, is it too much to expect the public to stop throwing usable paper and paperboard in the garbage? And for that matter, is it not possible that glass and metals can similarly be separated through official enforcement?

Within recent months, there has been an encouraging awakening on the part of government to the potential of recycling as a partial solution to the dilemma of solid waste. In his message to Congress proposing action against pollution on February 10th, President Nixon said, "We reprocess used paper less than we used to, not only adding to the burden on municipal sanitation services, but also making wasteful use of scarce timberlands." He then ordered a redirection of research under the solid waste disposal act to place greater emphasis on techniques for recycling materials.

In the interest of clarity, it should be pointed out that our nation's PERCENTAGE of reclamation is lower, but the actual tonnage of waste paper consumed last year is greater than at any time since 1945. What has happened is that the machinery of reuse has not kept pace with the machinery of production.

With this renewed emphasis on recycling, absent since the conclusion of World War II, we do not feel it is too much to expect government and the public to see the advantages in legislation that would keep fibers from being thrown in the garbage can. After all, 33 percent of the population currently lives in communities in which garbage or rubbish must now be separated for collection, according to Anton J. Muhich, Chief of Systems and Operations for the U.S. Government's Solid Waste Program. Certainly legislation would go far to guarantee a reliable flow of paper and paperboard AWAY from the dumps, and automation would do much to streamline the manner in which it would flow to the mill.

But there is also a necessity to carry the automation concept beyond the paper stock dealer and to the mill itself. While automatic balers seem to be the only practical answer to the dealer's problem, our mills must begin exploring the possibilities of automatic receiving systems for loose as well as for baled paper stock.

If legislation makes more paper available, it is certain that local organizations will increase their activity in the field of collection. And while this anticipated volunteer labor force would be welcomed, it usually only materializes on Saturdays and Sundays. What can even the most automated dealer do with a vast increase in volume all arriving on the same two days of the week?

The answer, it is believed, is the development of sophisticated receiving systems at the mills themselves, where loose paper can be automatically dumped, sorted, and fed to the pulpers as fast as the Boy Scouts can bring it. This is not to suggest that the need for dealers will be replaced. On the contrary, dealers will be required to arrange paper drives and to bale the tremendous volume of anticipated paperstock which must be warehoused, since the storage of loose paper is still impractical.

This brings us, then, to the third reason that America's cities must contend with 38 million reusable tons of garbage each year: the reliability of demand. History has shown us that as long as there is a strong demand by the mills, the paper stock dealer invariably comes up with the paper. Unfortunately, the demand for paper stock has not, historically, been very reliable. The peaks and valleys of demand mirror the peaks and valleys of the sale of finished goods. However, with the increased emphasis on conservation and the natural growth of consumer demand in the future, it is not inconceivable to expect the industry to have a dramatically increased need for the fruits of a recycling program.

Similarly, with a vastly increased volume of raw materials, American industry has historically found additional uses if the price is right. And the key to keeping the price right is the development of collection, processing, and receiving systems which utilize a maximum of efficiency with a minimum of labor cost.

When the Garden State Paper Company opened its first mill in Garfield, New Jersey, in 1961, the entire paper stock industry embarked on a revolution. The continued success, which enabled the installation of a second machine in Garfield in 1966, a new mill in Pomona, California in 1967, and a third mill outside of Chicago in 1968, has brought this company to a point from where they consume 360,000 tons of old newspaper each year. That is about 14 percent of all the newspaper currently being reclaimed.

We feel that the ability to use this volume of newspaper has helped stabilize the waste newspaper market—especially during the periods when the other mills' demand was traditionally low while, at the same time, the public was generating a large tonnage due to favorable weather conditions.

The reliability of supply and demand can only be established if government, industry, and the public response to the problems posed by solid waste disposal and to the potential destruction of our forests by embracing reclamation. It is not a project that any one group can or should embark on alone.

Those in the paper industry are not reluctant to meet their share of the responsibility, but they need government's help and leadership in meeting the overall problem head-on. An example of the paper industry's efforts to date is the National Committee for Paper Stock Conservation. This organization of the American Paper Institute has existed under various titles since the end of World War II. It spends thousands of dollars annually to tell the public how conservation can benefit from reclamation. And then, too, there is Keep America Beautiful—a five-year old organization sponsored by the paper industry and designed primarily to prevent litter.

But what of government's contribution? We recently received the preliminary conclusions of a solid waste survey conducted by one of our nation's most populous states. Nowhere in the entire report, which had surveyed solid waste management practices nationwide, was salvage for recycling mentioned once.

Similarly, many of our nation's suburban communities, deluged with mounting volumes of garbage, have laws specifically outlawing paper baling operations. Local government is going to have to drop the barriers and permit the expansion of these small plants in the areas where the need is greatest.

Even the President apparently realized that government had not been paying enough attention to reclamation when, in his message to Congress, he called for redirection of research. Not full steam ahead in a direction we had been going for years, but a redirection of thinking into an area where we can accomplish a greater percentage of reuse.

In addition, the government seems to have overlooked the fact that, as the nation's largest direct and indirect purchasers of paper products, it has an excellent opportunity TODAY to make a substantial contribution toward diminishing the amount of paper in solid waste by specifying that, when possible, its paper and paperboard need be met with reclaimed fibers.

It is suggested that industry, government on all levels, and the public should share the responsibility for meeting the solid waste problems of our cities, and that no single group should be asked to bear the complete expense or responsibility alone. And furthermore, the public does not have to be stimulated by a high price as an inducement to participate in the salvage program. The eventual reduction in taxes resulting from a reduced garbage volume, plus the contribution to the conservation effort, will possibly add to the price being paid for waste paper and provide the necessary incentives to make this link in the chain of reuse a profitable one.

One shining example of what can be accomplished when industry, government, and the public combine in working out solutions to common problems is illustrated by the newspaper salvage program well underway in Madison, Wisconsin. In a joint venture between the city and the Paper Stock Conservation Committee, approximately 40 percent of the newspapers entering the test area are being salvaged by the city for eventual remanufacture into newsprint, paper, and paperboard.

The program is a relatively simple one in terms of procedure. The home or apartment dweller — through a public relations effort which includes the placement of doorknob messages at every dwelling unit, public service announcements in various media, poster reminders in stores and shops, and planned word of mouth — is asked to bundle and tie his accumulated newspapers and place them alongside the refuse container at the curb. Specially compartmented packer trucks allow the newspapers to be collected separately, keeping them clean and free from contaminants. The newspapers are then sold to a local waste paper dealer who bales them for sale to nearby consuming mills.

The first 12 months of the program in the east side wards — representing a population of about 80,000 people — resulted in the collection of 918 tons of newspaper, conserving over 3,000 cubic yards of landfill space and more than 15,600 trees. It also eliminated both the disposal and transportation costs. The return on the sale of the newspapers reduced the number of dollars that would otherwise have come from the pocket of the Madison, Wisconsin taxpayer.

Variations on the project can conceivably work in every community. Where private haulers do the work of municipal collectors, the paper can be bundled and placed on the curb once or twice a month where local organizations (like the Boy Scouts) can pick it up and use the proceeds for equipment and supplies.

But in any case, the combined efforts of industry, government, and the public are essential for success. It is manifestly unfair to call on the glass, metal, and paper industries to provide essential commodities, and then ask them alone to pay to clean up the mess.

Unfortunately, there has been a stigma attached to the products manufactured from reclaimed fibers. Paper consumers normally expect inferior quality when told that secondary fiber has been used in the manufacture. While this concept is contrary to fact, the illusion still persists; and so, along with the other advancements mentioned today, consumer education will also be required.

U.S. Forest Service Resource Report Number 18 predicts that the demand for paper and paperboard in this country will double by 1985. We know from past experience that the price of wood will also increase. This would mean an astonishing consumption of 100-plus million tons. Pursuant to this projection, an Ad Hoc committee of the National Research Council, in a report guidelining *Policies for Solid Waste Management*, cites the need for supplying at least 50 percent of this growth from increased usage of recycled material. As the growth will be in the range of 50 million net tons, supplying 50 percent of the growth with recycled waste paper requires that we reclaim 25 more million tons by 1985. Combining this amount with our 1969 total of 11.4 million tons, we are being asked, in effect, to triple our consumption in 15 years.

However, there is no doubt that the activities of the virgin fiber supplier will have to be eventually curtailed, and it is to that end that we must prepare now for the most practical and sensible alternative. Any section of the country that can generate 300 tons of old newspaper a day, EVERY DAY, will be adequate to support another of our newsprint manufacturing mills.

There are no simple answers to any of our industry's problems, all of which must be solved in order to make recycling a practical solution for the solid waste dilemma, but there are answers. The Garden State Paper Company, Incorporated is optimistic. When their first mill was opened nine years ago, they were told that it would be impossible for them to do what they have continued to do profitably for nearly a decade now. And when one has seen a company built that could not be built, it is a little hard to shy away from things that supposedly cannot be done.

REFERENCES

1. Flint, Michigan, Residential. June, 1967. Unpublished tabulation by Bureau of Solid Waste Management, U.S.P.H.S., "Physical Analysis of Solid Wastes by Weight."

2. Atlanta, Georgia, *Municipal*, December 1968.

3. Susag, Russel H. (41.2%) "Developing Classifications

for Refuse," Solid Wastes Management, *Refuse Removal Journal*, March 1968, *Volume II*, No. 3, pp. 20, 37.

4. Bell, John M. (42.0%), "Characteristics of Municipal Refuse," Paper at National Conference on Solid Waste Research, University of Chicago Center for Continuing Education, Chicago, Illinois, December 1963, p. 37.

5. Luey, A. T., "Technological Advances in Secondary Fiber Usage," paper at *National Industrial Solid Wastes Management Conference*, University of Houston, Houston, Texas, March 25, 1970.

6. "Policies for Solid Waste Management," a report by the Ad Hoc Committee on Solid Waste Management, Committees on Pollution Abatement and Control, Division of Engineering, National Research Council, National Academy of Engineering, National Academy of Sciences, Washington, D.C. 1969.

Extraction System for Paper Fiber Reclamation from Municipal Wastes

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Black-Clawson Company

In recent years millions of words have been spoken and written on needs and methods for combating pollution - air, water, and now land. There probably was another 100,000 spoken and written for this proceedings. In recent times, and particularly here in Houston, much attention is being directed toward the solution of two problems - pollution and conservation. Perhaps the tone of the times has been very well said by Mr. Arsen Darnay, of Midwest Research Institute, when he recently wrote, "Solid waste is - waste. We do not wish to put money into the front end of the system just to get garbage out at the other end, no matter how efficiently it has been processed."[1]

We, in this country, are today recycling approximately 20% of our paper consumption back into into the production stream. Yet we are now burning or burying some 40 million tons of paper per year, and this figure will increase to 80 million tons in the very near future. In spite of our best efforts to segregate and collect paper products at the consuming source, a very high percentage will inevitably wind up as a major component of municipal solid waste - especially residential waste. Manual sorting of the paper products from the other waste is not economically feasible today, and, of course, will be even less so tomorrow.

An economically feasible, mechanical method of sorting paper fiber and other valuable constituents from the mixed waste is the urgent need today. We believe that such a method has been developed, and an explanation and photographs of such a system is the subject of this presentation - with the major emphasis on paper fiber reclamation.

Our company, the Black Clawson Company, has for over 100 years been a supplier of process equipment to the pulp and paper industry. Several years ago, we turned our engineers and scientists loose on the problem of processing solid waste, the object being to recover therefrom valuable materials to recycle into the economy, while simultaneously solving a disposal problem in an economic manner.

Since municipal solid waste is generally composed of 50% or more by weight of paper and paper products, these engineers and scientists applied their papermaking know-how and developed a wet processing system - a system resembling in some respects those employed in the secondary fiber paperboard mills. We have named the basic system Hydrasposal, and that portion of it devoted to fiber reclamation, Fibreclaim.

In a processing plant employing the Hydrasposal and Fibreclaim Systems, residential and commercial solid waste would be typically delivered in a packer truck. After being dumped, the waste would be pushed onto a conveyor which would feed a Hydrapulper. This is the machine normally employed in paper mills to convert bales of waste paper into a water slurry of cellulose fiber. You can visualize it as an overgrown Waring blender equipped with a several hundred horsepower motor. Through the action of the high speed motor in the bottom of the pulper, all pulpable and friable materials are reduced in size to the point where they will pass through 3/4" diameter holes located in the bottom, and are extracted as a water slurry with 3 1/2 - 4% solid content. Heavy objects such as metals, large pieces of glass, etc. are ejected through a large opening in the bottom of the pulper, conveyed away by a bucket elevator called a Junker, and then delivered to a conveyor from which the ferrous metals can easily be separated by magnetic means.

Extracted slurry contains almost all of the organic material - paper, food waste, textiles, plastics, rubber, grass, and wood - and some of the inorganics - most of the glass, bits of tin cans, etc. The slurry is now passed through a series of cleaning and screening equipment to separate it into its various constituents.

First, the bulk of the glass, metal, and other inorganic materials are removed in a Liquid Cyclone. These rejects, containing about 75% glass, may then be further treated to separate the glass into a reusable form. The glass particles at this point range in size from about 1/8" to 1/2".

From the Liquid Cyclone the slurry is now pumped to a defibering screen, called a VR Classifiner. At this point any flakes of paper in the slurry are broken down into discrete fibers, and long, stringy materials such as rags, string, twigs, etc. are separated from the fibers by passing through a screen with 1/8" diameter holes.

The slurry, now thoroughly defibered and coarse-screened, is pumped into a fine screen, with 1/16" diameter holes. The material that has passed through this screen now has essentially all of the papermaking fibers, plus fine dirt and fine, organic material.

The next operation is to remove the fine dirt, and this is accomplished by passing the slurry through high efficiency centrifugal cleaners.

The next step is to separate the long, desirable papermaking fibers from the remaining fine organic material. This we accomplish by employing a surface screen - or fiber selector, as we have called it. Here the long cellulose fibers are retained on the surface of the screen, and the unwanted fine materials are passed through the surface. If desired, two or more of these surface screens may be employed in series. Typically, we would arrange for the first screen to retain essentially only the very long fibers such as those used in the manufacture of kraft bags. A second screen would then retain the intermediate length fibers, more typical of newsprint and magazines.

The separated fibers are then cleaned and sterilized by cooking briefly in mild caustic, washed, dewatered, and baled for shipment to a paper mill or similar user of cellulose fiber. Of course, rejects from the first two screens and the fine rejects from the centrifugal cleaners and fiber selector screens are combined, dewatered, and burned in a fluid bed reactor.

The inert, innocuous ash from the reactor is combined with residues resulting from cleaning recovered metals and glass and is the only solid to be removed from the system. This represents less than 10% of the original weight and only a fraction of the original volume.

This is a wet system, i.e. water, pumps, and piping comprise the transportation system. Just as we can now do with our resources in solid waste, most of the water is simply recycled. However, to prevent organic build-up, a portion of the water must be bled from the system and given biological treatment. The treated water may be cycled back into the system, and the sludge from the treatment plan may be dewatered and burned in the fluid reactor.

The basic elements of the above described system have been incorporated into a pilot factory at Middletown, Ohio. The diagram and photographs are of this plant. We sincerely believe that this is the prototype of a system that is a means to reverse the money-in, garbageout cycle that we are now blessed with. Or at least to slow it down, drastically.

Let me give you some figures which our engineers have developed: A plant to process 500T/D of solid waste will cost, including land, buildings, utilities, and wastewater treatment facilities, approximately $4,200,000. From this plant we will produce the following:

100 T/D cellulose pulp,
50 T/D ferrous metals, and
50 T/D glass cullet.

Taking only nominal credit values for recovered material, net operating cost, including amortization, will be on the order of 70 cents per ton of solid waste delivered to the plant.

Doubling the plant size to 1000 T/D would result in a total capital cost of $7,600,000. From this plant we would produce the following:

200 T/D fiber,
100 T/D ferrous metals, and
100 T/D glass.

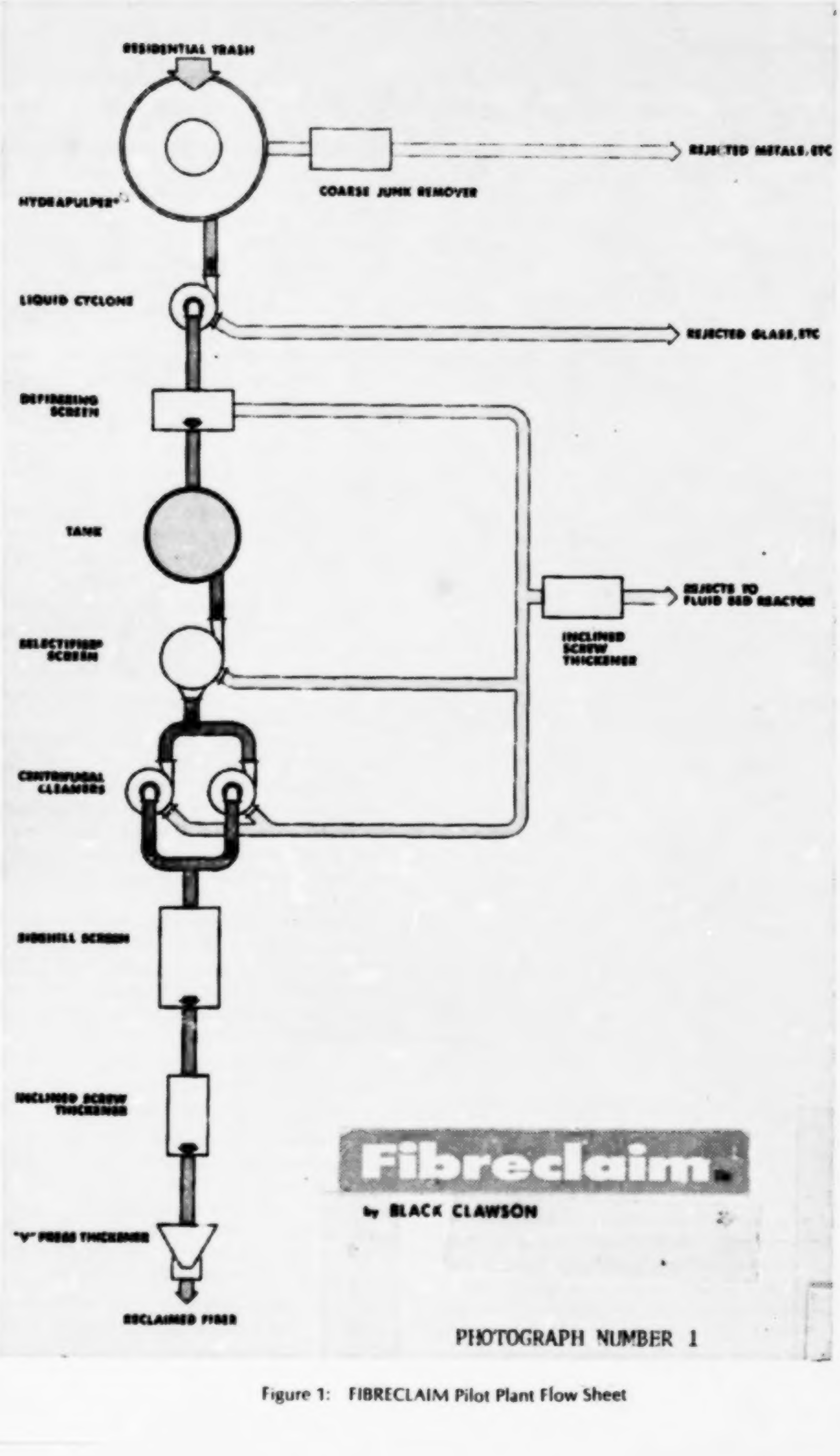
RESIDENTIAL TRASH
HYDRAPULPER®
COARSE JUNK REMOVER
REJECTED METALS, ETC
LIQUID CYCLONE
REJECTED GLASS, ETC
DEFIBERING SCREEN
TANK
SELECTIFIER® SCREEN
REJECTS TO FLUID BED REACTOR
INCLINED SCREW THICKENER
CENTRIFUGAL CLEANERS
SIDEHILL SCREEN
INCLINED SCREW THICKENER
"V" PRESS THICKENER
RECLAIMED FIBER
Fibreclaim
by BLACK CLAWSON
PHOTOGRAPH NUMBER 1

Figure 1: FIBRECLAIM Pilot Plant Flow Sheet

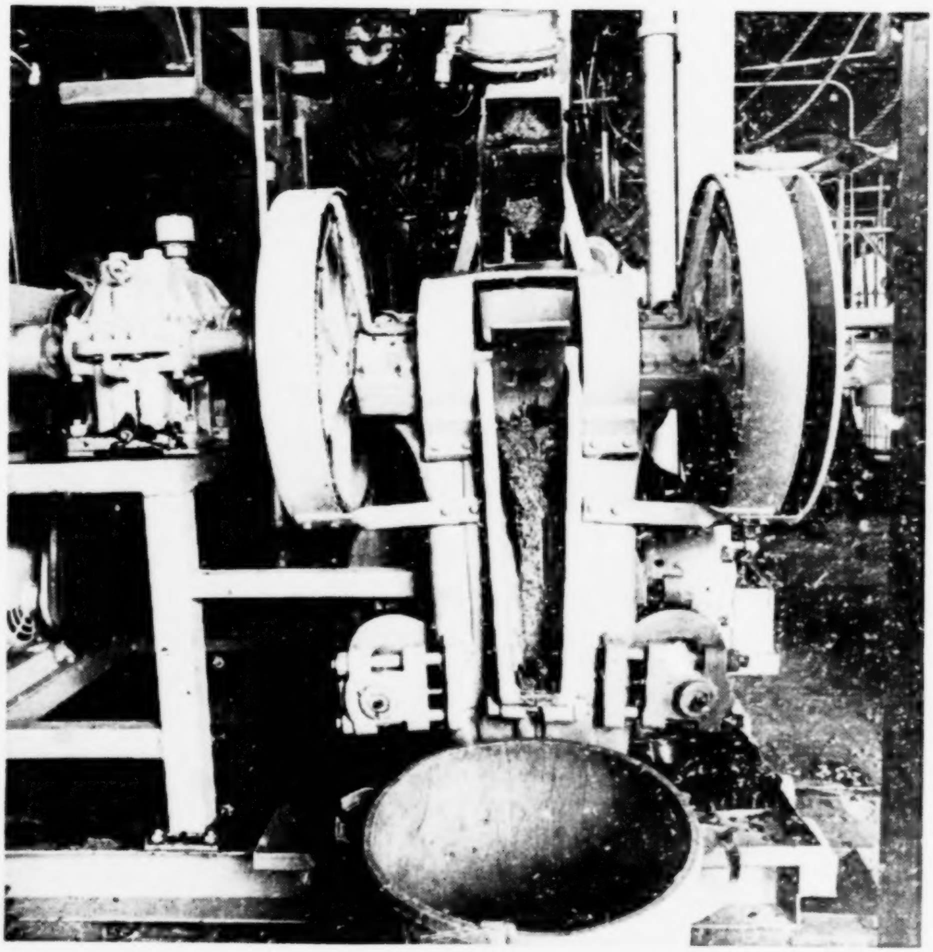

Figure 2 - View of "V" Press Thickener Showing Reclaimed Paper Stock

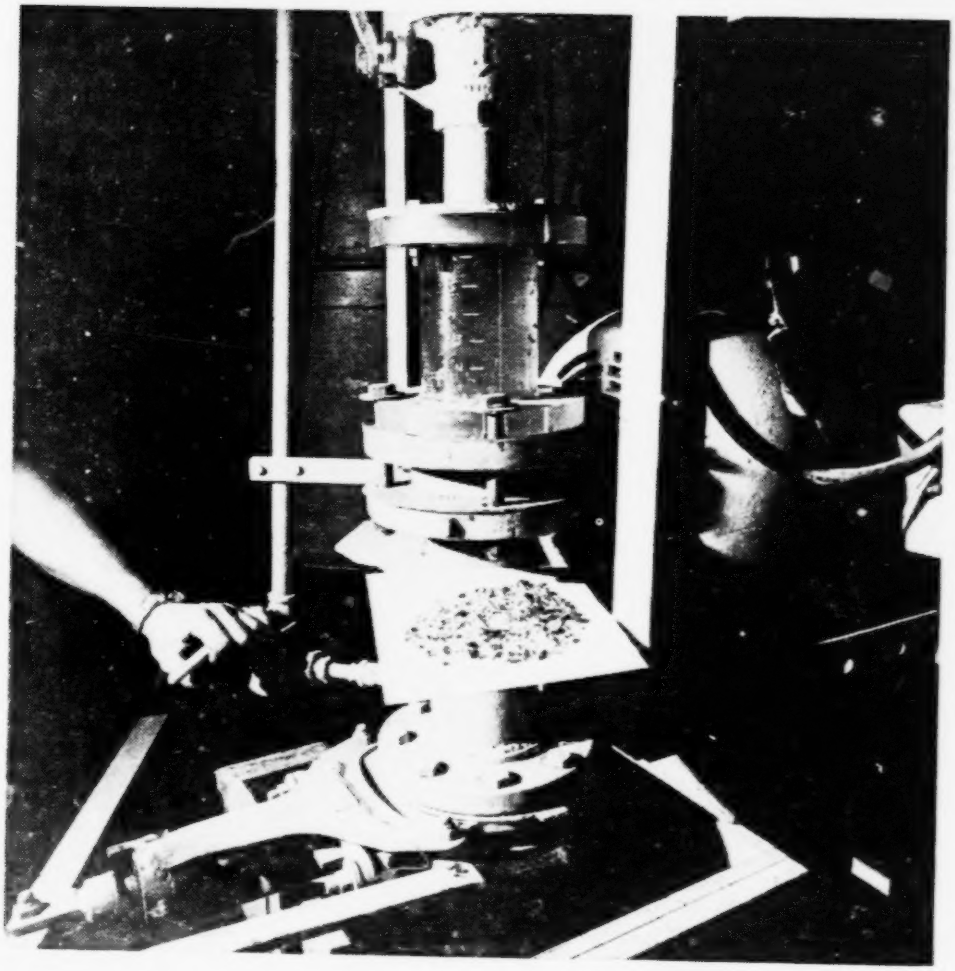

Figure 1. View of Cyclone Discharge Valves and Typical Rejected Material

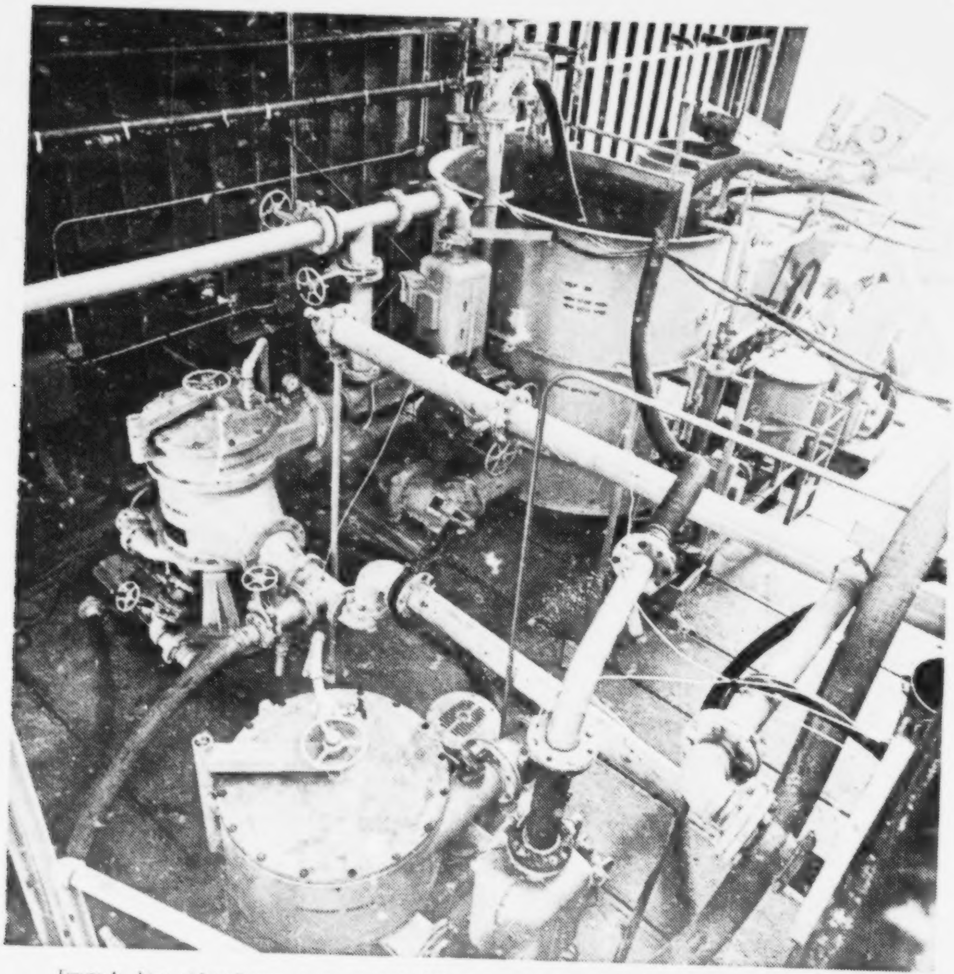

Figure 4: View of Fine Screens (foreground), Junk Remover, and Refuse Feed Conveyor (extreme background)

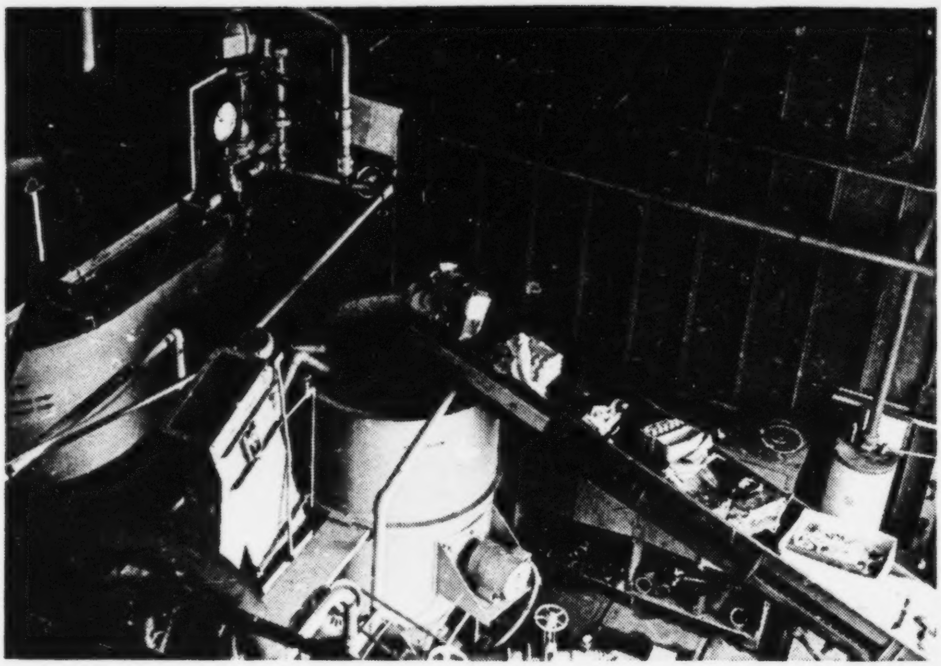

Figure 5: View (left to right) of Stock Tank, Junk Remover, Hydrapulper, and Feed Conveyor

Using the same conservative values, the net operating cost would be a *minus* $1.90 per ton.

Not mentioned earlier is that troublesome solid waste known as sanitary sewage sludge. This sludge, digested or undigested, which may cost up to $50.00 per ton to dispose of, can be blended with the screen rejects - with no added chemical or thermal treatment - and burned in the fluid bed. To accomplish this requires very little additional capital and essentially no additional direct operating cost.

Hence, if the solid waste factory is located in an area where sewage sludge is generated, and appropriate credit is taken for handling the sludge, even the 500 T/D plant can have a minus net operating cost.

It now appears that we are able to obtain an almost complete reclamation of our waste material, and the dollar estimates indicate that we can indeed reverse the money-in, garbage-out cycle mentioned earlier.

REFERENCES

1. Darnay, Arsen J., Jr. "Money In — Garbage Out," p. 8, *MRI Quarterly*, Winter 1969-70.

Chemical and Biochemical Aspects of Leachate

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Sanitary landfill practice can cause the production of polluting leachate and this negative factor retards the use of sanitary landfilling for solid waste disposal. Recent work reported by Fungaroli indicates that leachate will be produced in landfills where water, either surface infiltration or ground water, can move through the system.[1] In addition, moisture will be produced during the biochemical decomposition of the waste, but this quantity is usually negligible with respect to the total amount of moisture needed to bring a landfill field to field capacity.

Leachate can be unsightly, polluting and create undesirable nuisance conditions in the proximity of the landfill. If uncontrolled and allowed to stand on the surface of the ground, leachate can provide breeding places for insects and vermin, including flies, mosquitos and many forms of microbial life which cause emission of odors from the landfill site. The process of odor emission is associated with the phenomena known as putrifaction.

Leachate

Leachate is a complex mixture of dissolved and colloidal organic and inorganic salts and solutes. Refuse contains compounds (about five percent of dry weight) which are soluble in water and which can be extracted with water.[2] The distribution of organic and inorganic materials present will vary with the character of waste and specifically upon the amount of food wastes present. The amount of inorganic salts from solid wastes which are soluble in water can lead to some high concentrations of these salts in the leachate. Concentrations of chloride and iron as reported by Lane showed that the inorganic fraction of leachate can be very polluting.[3]

The character of leachate is difficult to express because, in addition to the type of materials in the landfill, the decomposition is a time-varying parameter. Decomposition of refuse is continually releasing secondary or intermediate products which are soluble where the primary product (e.g. cellulose) was not. As decomposition of the organic matter proceeds, cell walls are broken and inorganic material is not released. Hence, the factor of time is extremely important in defining the character of leachate.

In the study described by Fungaroli, a simulated sanitary landfill was carefully constructed using known quantities of leaves, cans, glass, paper, etc.[1] Rainfall and climate conditions were also simulated. Leachate production was carefully monitored and chemical analysis performed to describe the character of leachate. Release of the inorganic material and strength of the oxygen demanding fraction are presented in detail elsewhere.[4] This paper will deal with the general characteristics of leachate, in particular, the chemical and biochemical aspects.

High concentrations of inorganic salts could be quite polluting to ground water, but the salts are especially critical for they interfere with most analytical methods. High metals can retard natural biochemical oxidation of the organics present. The organic fraction of refuse, as it is collected in refuse trucks, is not soluble to any large extent and the organic concentration in leachate would not cause any serious problems for treatment, odor emission, or general nuisances. However, when degradation occurs in the solid organic fraction, leachate strength increases and the water moving through the landfill system becomes a solvent for removing the organic degradation products. The entire organic fraction of leachate becomes very complex because of the organics - inorganic interaction and includes some initial as well as several intermediate degradation products. The degradation products can result from aerobic or anaerobic decomposition depending upon age and depth of the landfill. Degradation of solid waste differs considerably from anaerobic decomposition are predictable, and the kinetics of decomposition have been investigated by Lawrence and McCarty and others.[5,6,7] In the decomposition of sludge by anaerobic processes, methane is the primary gas which is formed. In the decomposition of domestic solid waste methane also is one gas of concern, however, studies of Jenkins and Quasim and by Fungaroli and Steiner have indicated that other gases, in particular carbon dioxide, are produced in greater concentrations than methane.[8,4] This could indicate that the mechanisms of decomposition are aerobic rather than anaerobic.

All sanitary landfills will produce gases and leachate when decomposition of the organic material occurs. This is ample proof that a sanitary landfill can be considered to be a crude inplace treatment system and not simply a method of burial. This assumption can only be valid if there is a method of establishing criteria for evaluating the decomposition of organic material. Unfortunately, no such system exists. The degradation system in the landfill is very inefficient. Products of decomposition are produced in a random fashion, and they depend upon the proper environmental conditions for microbial growth and upon the presence of the necessary enzymes, nutrients, and food sources. No studies of consequence have been performed to study whether or not there are present in solid waste the necessary concentrations of metals and nutrients for optimum decomposition. Before these studies can be undertaken, it will be necessary to determine the specific microbial populations which are responsible for the biochemical decomposition.

Waste Decomposition

The factors of greatest influence upon decomposition are temperature, pH, and moisture content. Moisture is derived primarily from rainfall which means that the moisture content of the landfill area will be inconsistent. Until the landfill reaches field capacity, (no pore moisture) the decomposition of the waste will be retarded, and if decomposition is occurring it will be localized with possible stratification, with depth and will be greater in the landfill zone which is at field capacity. Areas that have not reached field capacity will have a lesser decomposition rate.

The main focus of this paper is to explore techniques which can be used in determining the nature of the organic fraction in leachate. In addition to determining the organic fraction, it is desired to predict the polluting potential of the leachate from the sanitary landfill, and what, if any, treatment can be given if leachate is collected and treated prior to discharge to surface streams or to the underground.

Many techniques have been developed and used successfully in estimating the biochemical characteristics of domestic sewage and polluted waters. The primary method used is called BOD (biochemical oxygen demand). Since BOD is a bio-assay technique, the microbial controls are very critical to the validity of results. High concentration of heavy metals, in particular iron, zinc and copper, are toxic to the microbes and made BOD values suspect. It is doubtful that many BOD values of leachate are meaningful except to establish a lower limit.

Table 1 contains the results of BOD analysis of different sewage treatment plant seeds in leachate from a simulated sanitary landfill. BOD tests were performed using the dilution technique and the seed waters were obtained from two plants (both activated sludge). One plant served a residential community and only domestic and commercial sewage were treated at the plant. In the second plant, several large industries discharged process waste waters including some copper and iron containing waste water. It was hoped that the biological acclimitization could occur in this plant and that the seed water would yield a true BOD. In addition to the two plants, seed water was obtained from both the primary and secondary tanks. It was hoped that a difference could be shown as a result of added acclimitization.

TABLE 1
BOD of Lysimeter Leachate

	PRIMARY	*SECONDARY*
Plant A[1]	2840	2360
Plant B[2]	1680	2040

[1] Plant A is an activated sludge plant w/no industrial waste.
[2] Plant B is an activated sludge plant w/about 50% IW.

It can easily be seen that there is virtually no correlation between the tests. While it is expected that there will be considerable variation in the BOD results, the almost 100 percent average difference is too large to be random.

COD tests on the sample were much more consistent and average about 8,800 mg/l. Domestic waste decomposition is not known at this time. Since the wastes degrade under a variety of conditions spread over a long period of time, the quantity and kinetics of product formation are impossible to hypothesize at this time.

In order to draw first run data on the analysis of leachate, many samples of leachate were analyzed. Table 2 is a list of all parameters measured. When data on each parameter were developed, one to one correlation techniques were undertaken. The results of their correlation are presented in Table 3.

It can be seen that there is a correlation between the dichromate oxygen demand and many of the parameters measured. In particular, the relationships are not limited to organic material concentration, but also include relationships with inorganic ions and radicals.

TABLE 2
Summary of Leachate Parameters

1. Iron
2. Zinc
3. Nickle
4. Copper
5. pH
6. Hardness
7. Phosphate (total soluble)
8. Sulfate
9. Chloride
10. Sodium
11. Suspended Solids
12. Total Solids
13. Ammonia Nitrogen
14. Total Nitrogen
15. Chemical Oxygen Demand (dichromate)

TABLE 3
Summary of Correlation Data
Leachate Parameters

1. COD = f(Fe, Ni, pH, TH, PO_4, SO_4, Cl, Na, SS, AN, TN, TS)
2. Fe = f(Zn, Cu, TH, SO_4, AN, TN, COD)
3. PO_4 = f(SS, TN, AN, COD, TS)
4. Na = f(pH, TH, Cl, COD, TS)
   Cl = f(pH, TH, Na, COD, TS)
5. pH = f(TH, Cl, Na, TN, COD, TS)

CONCLUSIONS

In determining the biochemical aspects of leachate from sanitary landfills, it is necessary to analyze the degradation product components which are produced. Neither the classical BOD test nor the chemical oxygen demand test is adequate to describe the composition and the potential degradation of the organic fraction. From the standpoint of interferences, the COD is more reliable and not subject to microbial inaccuracy from the heavy metals.

Many of the more sophisticated methods of analysis have not been proposed, although it will be necessary to develop data using these analytical tools if treatment of the leachate is contemplated. Some of these tools are the volatile acids determination and the use of total carbon or total organic carbon analyzers. The use of total carbon appears to be feasible if the leachate solution is relatively clean and not burdened with suspended solids. For leachate, this is not the case and preconditioning is necessary. The removal of these suspended solids is an analytical interference since the suspended solids adsorb some of the degradation products. The magnitude of the contribution of these products has not been determined.

Preliminary work using volatile acid data shows that the number of acids is large and cannot be easily separated. Further results of this work will be reported.

There does not appear to be a direct relationship between COD and BOD determinations. In general, the COD appears to be about 4-5 times greater than the BOD determination for the samples analyzed. Certainly this cannot be construed to be a general relationship, since many other variables would have to be studied.

REFERENCES

1. Fungaroli, A. A. "Hydrogeological Considerations in Sanitary Landfilling," presented at the National Industrial Solid Waste Management Conference, Houston, Texas, March 1970.

2. Schoenberger, R. J., P. W. Purdom, and N. M. Trieff, "Special Techniques for Characterizing Raw Refuse and In-

cinerator Residue," *Proceedings of 1968 National Incinerator Conference*, American Society of Mechanical Engineers, New York.

3. Lane, Burke E. and R. R. Parizek. "Leachate Movement in the Sub-Soil Beneath a Sanitary Landfill Trench Traced by Means of Suction Lysimeters," *Proceedings of Second Middle Atlantic Industrial Waste Conference*, Philadelphia, Pennsylvania, November 1968.

4. Fungaroli, A. A. and R. L. Steiner. *Final Report - A Study of Sanitary Landfills*, Drexel University, November 1969.

5. Lawrence, A. W. and P. L. McCarty. 'Kinetics of Methane Formation," *J. Water Pollution Control Federation*, Research Supplement, P. R1, February 1969.

6. Fair, G. M., E. W. Moore, and H. A. Thomas, Jr. *Sewage Works J.*, *13*, 1227 (1941).

7. Thomas, H. A., Jr. "Analysis of the Biochemical Oxygen Demand Curve," *Sewage Works J.*, 12, 504 (1940).

8. Quasim, Syed R. and Jerry C. Burchinal."Leaching from Simulated Landfills," *J. Water Pollution Control Fed.*, *42*, 3, 371 (March 1970).

Gas Generation and Movement In Landfills

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Problems Caused by Gas Produced In Sanitary Landfills

The following problems are caused by gases produced in landfills: accidental explosions, corrosion and chemical reaction in structural systems, and quality changes in well water.

The anaerobic decomposition of organic wastes produces carbon dioxide, methane, and traces of hydrogen, nitrogen, and organic volatiles. If the methane produced finds a closed area in which to congregate, an explosive mixture may result; a potential threat to the public health and safety may exist. There have been numerous incidents in this country and in Canada where dangerous explosions have occurred or persons have been seriously burned as a result of accidental ignition of methane gas which had accumulated near old landfills or refuse dumps.

If a totally carbon dioxide atmosphere, produced by a landfill, exists over a water surface, water will reach equilibrium with the carbon dioxide when the dissolved carbon dioxide level is 1688 mg/l.[1] The concentration of dissolved carbon dioxide varies linearly with the partial pressure of carbon dioxide in the atmosphere. Thus, in air (4 parts per 10,000), the normal equilibrium concentration is approximately 0.7 mg/l.

Dissolved carbon dioxide reacts reversibly with water to form H_2CO_3, and this compound dissociates to bicarbonate and hydrogen ions. If no secondary reaction with minerals occurs, this action will depress the pH of the solution toward a value of 4.3. The resulting solution, which is acid and saturated with high levels of carbon dioxide, is highly aggressive. High concentrations of dissolved carbon dioxide are reported to accelerate the corrosion of iron and steel and to promote the dissolution of lead.[2] In addition, free CO_2 in concentrations greater than 20 mg/l[3] will attack concrete sufficiently rapid to require protective measures.

In the event that waters high in dissolved carbon dioxide come in contact with mineral matter containing calcium carbonate, a reaction occurs which converts insoluble calcium carbonate to soluble calcium bicarbonate, thus increasing the hardness of water. In addition, soluble salts trapped within the calcium carbonate crystalline structure may come in contact with the water and dissolve, thus increasing the total dissolved solids within the water. This mechanism was thought to predominate in the "Mayflower" well incident.[4] Studies of this well indicated that the mineral being dissolved was dolomite.

Gas Production from Refuse

Little has been done to quantify gas production from sanitary landfills. Merz and Stone[5] constructed a lined refuse cell and attempted to quantify the gases produced during decomposition, but unfortunately leaks occurred and they report that they were unable to obtain the desired data.

For the most part, the organic portion of refuse consists of paper and cuttings from plants and wood; most of these consist of long chain linkage of hexoses, notably α and β glucose. The molecules have the molecular formula $[C_6H_{12}O_6]_\eta$. If this molecule is broken down anaerobically to methane and carbon dioxide, the resulting mixture would be 50 percent of each gas by volume. When proteins degrade to amino acids and finally to methane, carbon dioxide, ammonia, and traces of other materials result. The gases produced are approximately in the ratio 1:5:1 methane to carbon dioxide. The lipids found in landfills are for the most part esters of glycerol and long chain fatty acids. In these molecules, the ratio of carbon to oxygen is comparatively high; and as a result, the breakdown of these fats produces a gas very rich in methane (70 percent methane, 20 percent carbon dioxide). In anaerobic sewage sludge digestion, the final gas mixture approximates 2 to 1 methane to carbon dioxide (including the digestion of lipids). Accordingly, one might expect that refuse would produce gas of lesser strength with respect to methane.

In recent studies, Bell[6] found that a composite sample of an average municipal refuse consisted of the following:

Moisture	20.73 percent
Cellulose, Sugar, Starch	46.63 percent
Lipids	4.50 percent
Protein - 6.25 N	2.06 percent
Other Organics	1.15 percent
Inerts	24.93 percent
	100.00 percent

Each pound of this refuse after decomposition is theoretically capable of producing 2.7 cubic feet of carbon dioxide and 3.9 cubic feet of methane, or 6.6 cubic feet of gas per pound of refuse. If it is assumed that the refuse is compacted to a density of 500 pounds per cubic yard (twice this is not unreasonable), then one can expect each cubic foot of fill to produce a maximum of 121 cubic feet of gas.

In order to achieve this theoretical gas production, it is necessary to maintain a balanced condition. Such a condition would presume that all required micronutrients are available, that sufficient moisture is present for optimal enzymatic activity, and that an adequate buffer system is present. In the anaerobic digestion of sewage sludge, the moisture and buffer are more than adequate since moisture is in excess and annoniacal residues interacting with dissolved carbon dioxide provide the required buffer system.

It is commonly reported that when a digestor is just beginning to operate methane is not produced but copious quantities of carbon dioxide are observed. When the buffer system is established through hydrolysis and breakdown of proteins, the methane fermentation begins. In a landfill, the optimal buffer system is slow in establishing itself - probably due to the lack of moisture in the system. Thus, one commonly observes almost pure carbon dioxide being generated for long periods of time.

It seems likely that this carbon dioxide is produced due to aerobic processes combined with saprophytic anaerobic processes. The aerobic processes produce the required moisture to allow the buffer system to take hold and block the pores of the fill so that strict anaerobism can result. The result of this is the long periods of time noted[8] for methane fermentation to begin. Undoubtedly, small areas suitable to methane fermentation are found, and gradually this spreads until the whole fill is producing methane.

When water can enter the fill through the surface (or ground) the whole process may be greatly accelerated. Thus, when one builds a dry fill, one is really constructing a "time bomb" which can go off either naturally or artificially, depending on events occurring after the fill is complete (such as unexpected raising of the water table or ponding of rainwater which enters the fill).

Gas Movement

The mass transfer problem occurring in and surrounding landfills can be divided into three phases:

a. gas flow through the fill,

b. gas flow in porous media surrounding the fill,

c. gas flow through "semi" barriers such as moist soils.

The transfer of noncondensing gases through porous solids can occur by the following three mechanisms: molecular effusion (the Klinkenberg effect),[9] diffusion, and convection (flow due to a pressure gradient). In a particular case, one mechanism may dominate or the flow may consist of two or three mechanisms acting with equal effect.

In effusive flow, the fluid does not act as a continuum, but rather each molecule in the fluid behaves as an individual particle. When the molecular mean free path is much smaller than the characteristic dimension of the pore spaces, the fluid acts as a continuum and effusive flow is negligible. For gases at atmospheric pressure and normal temperatures, the mean free path is of the order of 10^{-5} cm (1000 Angstroms). Thus, for very fine grained soils (eg., clay), effusive flow can be important. These soils have a tendency to retain moisture, and therefore are frequently impervious to gas flow by any mechanism.

Diffusion is the tendency for a fluid, by its random molecular motion, to distribute itself uniformly throughout the volume it occupies. The basic rate equation for diffusion is Fick's Law. This law, combined with the conservation of species equation, the continuity equation, and the momentum equation, must be solved in order to predict the flow field due to diffusion.

The third mechanism for flow of fluids through a porous media is convection. In this context, convection is intended to mean flow caused by a pressure gradient. At lower flowrates (such that the Reynolds number is less than unity), inertial effects can be neglected and Darcy's law is the basic rate equation.[10]

Since the fill contains voids whose characteristic dimension is much larger than that of the voids in soil, it will be assumed that gas may move freely within the fill proper. (This assumption loses validity as the moisture content of the fill increases, and thus, additional information might be required to properly evaluate this factor.)

Example

The above concepts can be demonstrated quantitatively by means of an example. Consider a fill 1000 feet x 1000 feet x 100 feet deep, surrounded by a sandy soil. From the above discussion on gas production one sees that this particular fill could produce a maximum of 1.21×10^{10} cubic feet of gas over its lifetime. In order to further simplify the problem, assume that the sides and bottom of the fill are an effective gas barrier. Thus, the total gas production must leave the fill through the top surface area (10^6 square feet).

By means of this example, it can be demonstrated that, for many typical landfill conditions, convective gas flow as described by Darcy's Law is an appropriate model. This will be done by showing that (a) molecular effusion is negligible, (b) molecular diffusion is negligible, and (c) inertial effects are negligible.

As was stated above, molecular effusion is only important when the mean free path of the gas molecules is greater than or about equal to the characteristic dimension of the porous soil. For gases at conditions near atmospheric pressure and temperature, the mean free path is of the order of 10^{-5} cm or 3.3×10^{-7} feet. The characteristic dimension of typical sand[9] is of the order of 2×10^{-4} feet. Thus, for sand soils and for soils whose grain size is as much as 1/1000 that of sand, molecular effusion will be negligible for most cases of practical interest.

A conservative model for molecular diffusion is one in which the presence of the soil was not felt by the diffusing gas molecules. This model will over-predict gas flowrates. This is equivalent to the diffusion of a gas through a stagnant air layer. For the one-dimensional case, the mass flowrate per unit area is given by the following:[9]

$$\frac{M}{A} = \frac{DMp}{RT\Delta x} \ln \frac{p}{P_a}$$

A description of the terms used in this equation and typical values for the present example are:

D = diffusion coefficient 0.62 ft^2/hr (Rf9, Table A-8)
M = molecular weight of diffusing gas 30 (M = 16 for CH_4 and 44 for CO_2)
p = atmospheric pressure 14.7psia
R = universal gas constant = 1545.3 ft lb/lbm°R
T = absolute temperature ≈ 520°R
Δx = thickness of soil covering the landfill ≈ 10 ft
P_a = partial pressure of air at the top surface of the landfill ≈ 8 psia

Using this data the mass flowrate per unit area due to molecular diffusion is $\frac{M}{A} \approx 3 \times 10^{-3}$ lbm/hr.-ft^2. Using an average density of the gas of 0.07 lbm/ft^3, the volume flowrate per unit area is $\frac{q}{A} \approx 4.3 \times 10^{-2}$ (cu. ft. of gas/hr.)/sq. ft. area. The total gas production rate per unit area (see previous section) was 1.12×10^4 cu. ft. gas/sq. ft. area. Thus, the time required for all of the gas to escape by diffusion is 3×10^5 hours or 34 years. It is known that when the biological decomposition of landfill materials begins the rates are much larger than this. In view of the results presented below for convection, it is seen that molecular diffusion is not the dominant mechanism for gas transport under these conditions.

For convection gas transport through a porous media, the rate equation is Darcy's law, if inertial effects are negligible (RF 8). According to references, inertial effects are negligible if Re < 1.0 where:

$$Re = \frac{\rho V d}{\mu}$$

d = the characteristic dimension of the particle $\approx 2 \times 10^{-4}$ ft.
ρ = the gas density ≈ 0.07 lbm/ft.^{3}
V = the superficial velocity, and
μ = the viscosity coefficient $\approx 10^{-5}$ lbm/ft.sec.

If one considers the critical case where the Reynold's number is one, the volume flowrate of gas per unit area must be:

$$\frac{q}{A} = \text{(cu. ft. gas/sec.)/sq. ft. area}$$

For the total production rate stated above, this would require that all of the gas escape from the landfill over a period of 4.75 hours. Experience shows that this is clearly not the case. Hence, inertial effects can be neglected.

The above analysis indicates that for these conditions (which are typical of landfills), the rate equation for gas flow through landfills is Darcy's law:

$$\vec{q} = -\frac{kA}{\mu}\left(\nabla p + \rho\vec{g}\right)$$

$\vec{q}$ = volume flowrate of gas
k = permeability
A = area perpendicular to the flow vector
μ = viscosity coefficient of the gas
p = gas pressure
ρ = gas density
g = acceleration of gravity

It can be easily shown (compare equations 16.22 and 16.24 of Reference 8) that for conditions typical of landfills the gas can be assumed to be incompressible. Under these conditions and for one-dimensional flow perpendicular to the earth's surface, Darcy's law yields:

$$q = -\frac{KA}{\mu}\left(\frac{\Delta p}{\Delta x} + \rho g\right)$$

A dimensionally convenient version of this equation is (Reference 8, equation 16.2):

$$q = -6.34\,\frac{KA}{\mu}\left(\frac{\Delta p}{\Delta_x} + \rho g\right)$$

where the dimensional units and typical values for the present example problem are:

K = Darcy's 5 for sand
A = sq ft = 10^{6} for conditions of example
μ = centipoise = .015 for gases of interest
$\frac{\Delta p}{\Delta x}$ = psi/ft = 0.014 for conditions of example (this corresponds to a gas pressure of 3 in H_2O gauge)
ρg = psi/ft = 0.004 for conditions of example
q = cu ft gas/day

Inserting these values, the gas flowrate per unit area becomes

$$\frac{q}{A} = 21.1 \text{ (cu ft gas/day)/sq ft area}$$

The total gas production for the landfill of this example would thus escape in 600 days. This is known to be of the proper order of magnitude.

This example has established that for conditions typical of landfills:

a. Molecular effusion is negligible for most cases;

b. Molecular diffusion is negligible compared to convection;

c. In convection, inertial effects are negligible and compressibility effects are negligible;

d. The appropriate rate equation is Darcy's Law.

Multidimensional Gas Flow

For the multidimensional flow of an incompressible fluid in a porous solid under conditions such that inertial effects can be neglected and using Darcy's rate equation, the law of conservation of mass yields (eq 16.31, Reference 8) Laplace's equation:

$$\nabla^2 p = 0$$

Thus, the flow can be described as potential flow; and numerous existing techniques can be used to solve these problems. One method which is very convenient — especially for two-dimensional cases — and accurate is analogical potential mapping. For the two-dimensional case, the flow of electricity in a conducting paper also obeys Laplace's equation. Thus, an electrical analog to the gas flow problem can be established.

The results of an analogical analysis of the landfill problem of the above example, but with no barriers along the sides or bottom and with a water table 180 ft below the fill, is shown in Figure 1. Isobars (labeled as percentage of the pressure drop between the fill and the surface) and streamlines are shown. If this fill were covered by an impervious clay layer along the top surface and an impervious liner were placed along the bottom of the fill, the flow map would appear as in Figure 2.

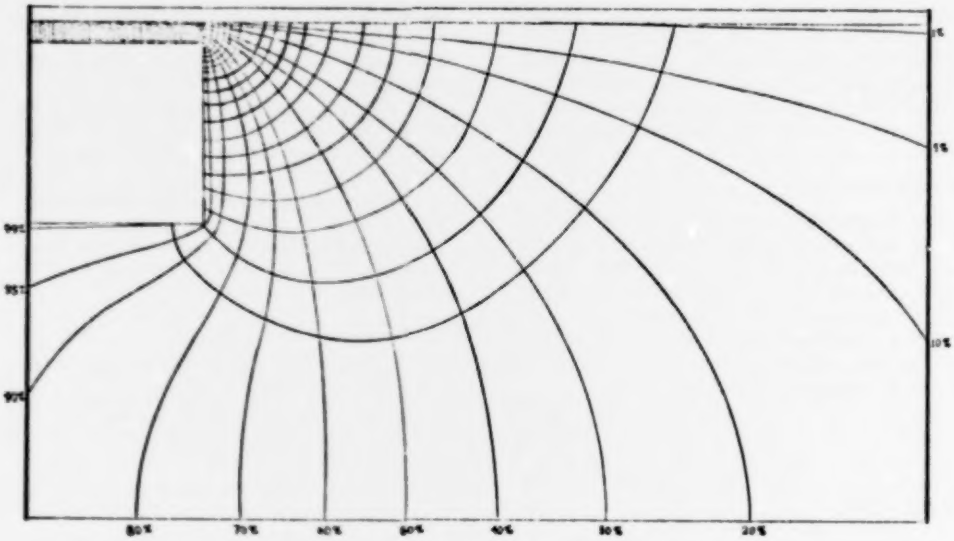
1%
5%
10%
99%
95%
90%
80%
70%
60%
50%
40%
30%
20%

Figure 1: Gas Flow Field Beside a 1000 X 1000 X 100 Ft. Landfill With No Barriers

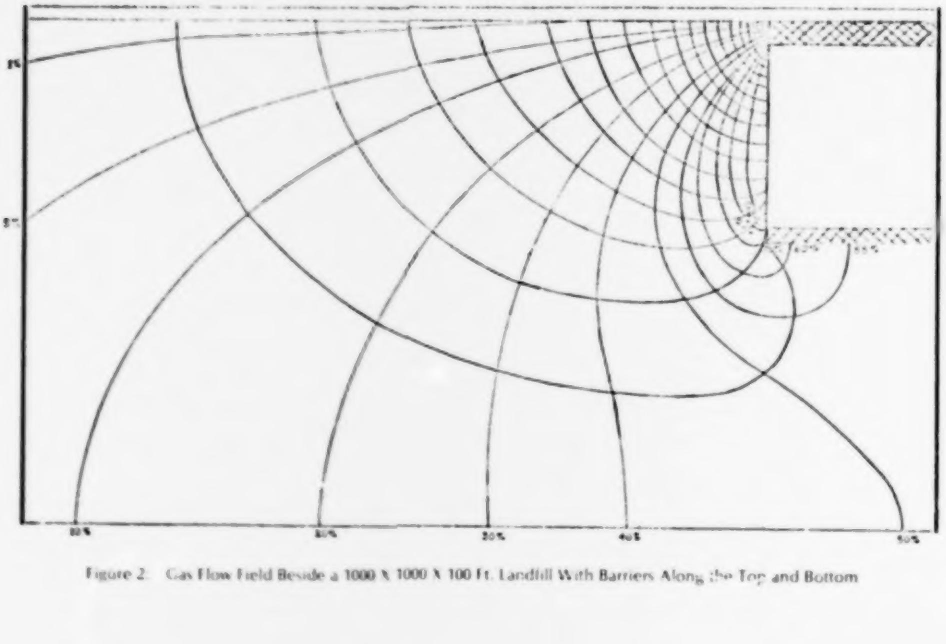
1%
5%
10%
20%
40%
50%

Figure 2: Gas Flow Field Beside a 1000 X 1000 X 100 Ft. Landfill With Barriers Along the Top and Bottom

The number of flow paths is reduced from 635 to 35 when the barriers are added. Since the flow pattern to the side of the fill is not significantly perturbed by the addition of the barriers, one can conclude that the gas flowrate at any point to the side of the fill will be 18 times greater due to the presence of the barriers.

CONCLUSIONS

1. It is possible to develop a model for any landfill with respect to gas movement. For most cases, this requires the use of flow net plotting combined with diffusion analysis on the outer periphery of the convection flow net.

2. Since gas generation is a certainty in sanitary landfills, its occurrence, and movement should be designed into the system.

3. Where soils are porous, landfills should be underlain with a moist clay barrier which will serve to contain leachate and force the gas flow net upward, thus reducing the area influenced by gas movement.

4. A level of gas emergence which is permissible should be established. This allowable flowrate should take into consideration both explosion hazards and the effects of the gases on the root zone of various types of plant life.

5. In order to perform a competent design, the following variables must be evaluated:

a. The relationship between gas permeability and moisture contents;

b. The relationship between permeability diffusion and moisture contents;

c. The rate of moisture evaporation and diffusion from fine soils used as barriers;

d. Enumeration of the rate of solution of carbon dioxide in ground water flowrate;

e. Enumeration of the mixing of carbon dioxide laden waters with the rest of the ground water mass as a function of flowrate;

f. A listing of mineral substances and their occurrence - are subject to solution at the pH levels developed with carbon dioxide saturation;

g. The relationships between moisture content, degree of mixing nutrient supply, and availability of a buffer system in decomposing refuse as a function of gas quality and rate of production.

REFERENCES

1. Anon. *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Company.

2. Bado, A. A. "Composition of Water and Interpretation of Analytical Results", *Journal of AWWA*, 31, 1965 (1939).

3. Terzaghi, R. D. "Concrete Deterioration Due to Carbonic Acid," *Journal British Society of Civil Engineers*, 36, 146, (1949).

4. Gram, A. L. "Effects of Refuse Dumps on Ground Water Quality," *The Resources Agency of California Publication #24*, (1961).

5. Merz, R. C., and R. Stone. *Factors Controlling Utilization of Sanitary Landfill Site*, University of Southern California, March (1966).

6. Bell, J. M. "Characteristics of Municipal Refuse", *Proceedings, National Conference on Solid Waste Research*, APWA Special Report No. 29, February, (1964).

7. Engineering - Science, Inc. "In Situ Investigation of Movements of Gases Produced from Decomposing Refuse", California State Water Quality Board, (1964).

8. Richardson, J. G. "Flow Through Porous Media", Section 16, *Handbook of Fluid Dynamics*, McGraw Hill, (1961).

9. Muskat, M. and R. D. Wyckoff. *The Flow of Homogenous Fluids Through Porous Media*, J. W. Edwards, Inc., (1946).

10. Holman, J. P. *Heat Transfer*, McGraw Hill, (1963), pp. 332-334.

A Summary of Sanitary Landfill Guidelines

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It is estimated that over 100 million tons of industrial solid wastes are generated annually.[1] A number that large, whether in tons of solid waste or the dollar costs of disposal, is not easily comprehended, but the smoky, unsightly, and smelly dumps, in which a large portion of these wastes are currently being disposed of, are all too evident. Recycling and recovery of wastes can reduce the quantity to be disposed, but will rarely eliminate the need for disposal of some portion of an industry's wastes.

Dumping is not only unnecessary, but is a threat to public health and endangers the air and water resources of man. As the public, the ultimate consumer, becomes increasingly aware and concerned about its environment, industry will benefit by seeking more efficient and sanitary methods for solid waste disposal.

Technology is available today to economically dispose of most industrial wastes without endangering air and water resources and public health. Dumping, however, is still the prevalent method of disposal for community and industrial wastes because of (1) the diversity of definitions for an acceptable disposal, (2) unwillingness to spend the extra fifty cents or dollar per ton for acceptable disposal operations, and (3) the difficulty of gathering available technology to solve a particular disposal problem.

The Bureau of Solid Waste Management is currently preparing a series of guidelines that will summarize available technology, outline acceptable levels and methods of disposal, and define solid waste terminology. These publications will assist and encourage governmental agencies, industry, and the public to seek and finance acceptable solid waste treatment and disposal systems.

Incinerator Guidelines 1969 has been completed and will soon be available.[2] Work is progressing on a glossary of solid waste terms and on guidelines for closing open dumps. Our major emphasis now is to complete *Sanitary Landfill Guidelines 70.* These publications will be revised when necessary to reflect improvements in technology. Although we now have sufficient technology to provide better disposal of solid wastes than is currently practiced, there is a definite need for more information on presently used disposal methods, as well as on new methods being developed.

The sanitary landfill guidelines primarily concern disposal of municipal solid waste, but the basic processes are the same for disposal of most industrial waste. Strict adherence to the guidelines may not be necessary for a few industrial wastes; for example, daily earth cover is not necessary for adequate disposal of waste foundry sand. In other cases, a particular industrial waste may have handling and disposal characteristics beyond the scope of these guidelines, and specialized handling and disposal methods would have to be used.

Definition

The Bureau of Solid Waste Management defines a sanitary landfill as an engineered "method of disposing of solid waste on land by spreading the waste in thin layers, compacting the waste to the smallest practical volume, and covering the waste with earth cover each day in a manner which prevents environmental pollution."[3] Application of the last phrase of this definition, the key to sanitary landfilling, presents the most difficult problems in site selection and operation. Open dumps, which are the opposite of sanitary landfills, involve no supervision or effort to protect the environment. Even with compaction and cover, a disposal site that contributes to pollution of underground aquifers or surface waters is not a sanitary landfill.

Site Selection

Selection of a sanitary landfill site requires consideration of: (1) the type of waste to be disposed; (2) water polluting contaminants that may be expected as a result of decomposition or other reactions; (3) site hydrology, soil conditions, geology, and topography; (4) social-political restraints; and (5) the ultimate cost of land, cover material, haul distance, improvements, etc. Development of a systematic selection process is difficult because these factors are interrelated and some cannot be quantified. Regardless of other factors, the primary concern in site selection should be protection of the environment.

Types of Industrial Solid Waste

The composition of municipal and industrial wastes varies considerably, both chemically and physically. The portion of industrial solid wastes from shipping, office, and plant operations, which consists of mixed paper, cardboard, metal, wood, and food wastes, is similar to municipal wastes. Cardboard frequently is salvaged from industrial wastes; but generally, the wood, metal, paper, and food wastes are wasted.

Process wastes, directly derived from manufacturing or processing a saleable product, are usually peculiar to a particular industrial process or plant operation. As with the foundry sand previously mentioned safe disposal may be very simple and inexpensive; because of toxicity or other objectionable properties, disposal of other wastes may be difficult. For example, if even small quantities of phenolic material leach into a useable aquifer, severe taste and odor problems may result.

There is a general absence of specific information on the physical and chemical properties of the many types of industrial materials entering the solid waste stream. Both quantitative and qualitative data are needed to bring about safe and economic management of our nation's industrial solid wastes.

Water Pollution Potential from Decomposed Contaminants.

Water percolating through solid waste can remove microorganisms and soluble chemicals that may adversely affect our environment and even menace public health if they enter useable aquifers or surface waters. Although the amount and composition of contaminants from deposits of municipal solid waste are reported, very little information is published concerning contaminants from industrial solid wastes. The COD of the leachate that first emanates from a landfilled municipal solid waste deposit can be as high as 17,000 to 50,000 mg/liter.[4,5] Introducing such a high waste load to a stream would very likely upset its ecology. Reasonably, then, many deposits of industrial solid waste would have an equal or even greater potential for water pollution.

Hydrology.

Site hydrology affects the type and rate of decomposition, the amount and rate of leachate and gas production, operation of the site, and erosion of the cover material. Surface runoff characteristics of the watershed in which the site is located and characterization of aquifers underlying the site are essential to evaluate the effect of a landfill operation on the environment. In general, there are two basic guides concerning site hydrology: (1) the amount of surface water entering a fill should be kept at a minimum to control or completely eliminate leaching and (2) decomposable or readily soluble waste should not be deposited directly in groundwater.

Soil Considerations.

The purpose of soil cover for solid wastes deposited in landfill is to control flies and rodents, maintain an aesthetically unobjectionable site, and control gas and water movement. Sufficient volumes of soil for daily and final cover should be available at or nearby the site. Many soils may be suitable for daily cover if adequate thickness is applied; six inches of compacted sandy loam is sufficient to prevent the emergence of flies.[6] The thickness of final cover depends on soil type and planned use of the completed site. A minimum of two feet is recommended. Greater thickness is often required to support trees and deep rooted plants.

The natural soil formation in which the waste is deposited provides an opportunity for attenuation of contaminants carried in leachate. Prevalent attenuating mechanisms are filtration, ion exchange, adsorption, precipitation, complexing, and biodegradation. Their effectiveness depends on the structure and mineralogy of the soil and the biota present in the soil.

Geology.

The potential for groundwater and surface water pollution is directly affected by the type, composition, and sequence of earth materials underlying and surrounding the sanitary landfill. Permeability, the most important geologic characteristic, influences the volumes and rates of leachate and groundwater flow; large quantities may flow through gravels and the open channels of fractured limestone, whereas extremely slow movement can be expected through tight clay-shale and slitstone formations.

Topography.

Any topography may be used for a sanitary landfill site, but some landforms necessitate variations in operational techniques and require possibly expensive site improvements. Canyons, ravines, and quarries that are normally more efficient from a land-use standpoint may, however, suffer from a shortage of cover material. Flat areas usually have greater soil depths, and both area and trench methods may be used. Marsh and tidal lands can also be filled, but they usually require expensive preparation and careful design. Marshland, of little value as real estate, may have considerable ecological value as nesting and feeding grounds for wildlife, however, and this must not be overlooked.

Failure to consider the hydrology, geology, soil properties, and topography of a site may necessitate construction of leachate collection and gas control systems after construction of the sanitary landfill.

Social-Political Restraints.

A sanitary landfill is subject to social and political restraints that must be dealt with during the site selection process. Often the greatest problem in obtaining a site is the objection of nearby landowners and citizens concerned about the environment. Based on the past record of poor disposal practices, their objections are justifiable. There is a need, therefore, to meet with concerned citizens in the planning stage to describe the sanitary landfill operation and differentiate it from dumping.

Zoning laws and licensing may influence site location, and approval by the county or state regulatory agencies may also be needed before operations begin. Because many industrial wastes can be safely handled and disposed of along with municipal solid waste, industries and the municipality should cooperate. Examples are waste pigments, sludges cannery wastes, ground rubber and other industrial wastes that may be difficult to handle individually. By combining industrial and municipal disposal, more efficient and satisfactory disposal of all the waste in a community may be achieved; this, in turn, should reduce the objections of nearby landowners and concerned citizens.

Economy of Disposal.

The cost of land, cover material (if imported or hauled long distances), equipment, site improvements, and haul distance from the generating source to the disposal site must all be considered because the site selected is ultimately based on cost. Since waste is of no value to us, the cost of disposal has always been kept as low as possible. The environment, however, should not be sacrificed in the interest of low-cost disposal.

Design and Operation

Designing a sanitary landfill includes development of an operational plan and design of site improvements. These are based on considerations of site selection which have already been discussed.

Site Improvements.

All sites require improvements before operations begin, basically to permit year-round use. Off-site roads may need to be constructed or improved. On-site roads must be constructed and should be passable in wet weather. Water is needed for fire protection and dust control. Electricity is necessary if disposal operations are conducted at night. An equipment maintenance shed, operator's office, sanitary facilities, and radio or telephone are also desirable.

Drainage works, leachate collection, and gas control systems should also be designed, located, and constructed where needed. Drainage from upland areas should be diverted around the site. In some soils, drainage ditches may also be used to lower the groundwater table. Drainage through the site or to collect leachate can be accomplished with French drains. In some cases, the leachate may need treatment, and for some industrial wastes, the leachate may be processed to recover some saleable material as is done with copper tailings.

Gas control may be needed with highly organic industrial wastes. The most common method is to use soils of selected permeability that direct the venting of decomposition gases. As an example, an impermeable top cover will direct gas movement to the sides of the fill where the gas can be vented to the surface through gravel-filled interceptor trenches. Another approach is installing vertical pipes through the cover to various depths within the waste to vent gases to the atmosphere. Pumped exhaust wells may be needed in more difficult situations. Solid waste deposited in some permeable soil and bedrock formations may require an impermeable lining to control gas and leachate movement. Well-compacted clays capable of retaining a high amount of moisture are considered suitable. Some plastics and asphaltic materials may also be suitable, but often high cost and placement difficulties are encountered.

Although these gas control methods can be effective, sites requiring elaborate control devices should be avoided because of the long decomposition time for most solid wastes (50 years or more is common). Most control devices require inspection and periodic maintenance to ensure safe, effective performance.

Operational Plan.

The operational plan details the methods and procedures to be used in constructing and operating the fill: the fill sequence, cover material excavation, placement of daily and final cover, and also the handling and placement procedures for all wastes, particularly liquids and hazardous solid wastes.

The plan may describe a record-keeping system that would provide management with time and cost records and the rate of land use, and that could be used to evaluate the many alternatives for disposal. A sample cost accounting system for sanitary landfills has been developed by the Bureau for this purpose.[3]

Equipment.

Most landfill operations use large earth moving equipment such as crawler and wheel tractors and loaders. Road compactors and log-skidders, modified and equipped with large blades and steel wheels, may find application in a multiple machine operation. A comparison of machine capabilities indicates there is no universal machine. As an example, a crawler tractor will not be very good for hauling cover material, whereas a wheel loader would be good for short hauls. Accessories are available that increase machine capacity, protect the engine and moving parts from excessive wear, and protect the driver from injury.

The Completed Fill

One of the great advantages of sanitary landfilling is reclaiming marginal land. All uses of the completed fill, however, require certain precautions against undesirable settlement, leaching, and gas movement. The most problem-free method of construction employs solid fill islands, although piles and foundation systems normally used on easily consolidated and deformable soil have been used successfully.

An industry may use completed landfills for such things as parking lots, storage areas, and warehouses. Because of the possibility of differential settlement, concentrated loads should be avoided. When structures are placed on fills made of organic materials, sufficient ventilation will be required to avoid concentration of decomposition gases. Allowances must also be made for possible differential settlement of utility lines within the fill and for their safe hookup with buildings.

SUMMARY

The unacceptable practice of dumping continues to be the prevalent method for disposing industrial solid waste. The Bureau of Solid Waste Management is developing *Sanitary Landfill Guidelines 1970* to gather available technology and provide guidance for land disposal of solid waste that prevents environmental pollution.

To select a suitable sanitary landfill site, the type of waste to be disposed, the contaminants that might be expected from these waste, the suitability of the physical characteristics of the site, social-political restraints, and the relative economy of disposal all must be considered. Gas movement and leachate control are essential to protect the environment and may require specialized site improvements. The sanitary landfill should be operated according to an operational plan that details the sequence of filling, the handling and placement of the waste, and the application of cover material. When completed, the site may be used for other purposes. Sanitary landfilling, therefore, is not only an acceptable method for land disposal of solid waste, but also a means of reclaiming land.

REFERENCES

1. Combustion Engineering, Inc. *Technical-Economic Study of Solid Waste Disposal Needs and Practices.* Public Health Publication No. 1886. Washington, U.S. Government Printing Office, 1969.

2. DeMarco, J., D. J. Keller, J. L. Newton, and J. Leckman. *Incinerator Guidelines — 1969.* Public Health Service Publication No. 2012. Washington, U.S. Government Printing Office, 1969.

3. National Solid Wastes Management Association and the Bureau of Solid Waste Management. *Sanitary Landfill Opera-*

tion Agreement and Recommended Standards for Sanitary Landfill Design and Construction. (sw-20ts) Cincinnati, U.S. Public Health Service, 1969.

4. *Investigation of Leaching of a Sanitary Landfill.* Publication No. 10. State Water Pollution Control Board, Sacramento, California, 1954.

5. Fungaroli, A. A. *Summary Report - Pollution of Subsurface Water by Sanitary Landfill.* Unpublished data from PHS grant No. 5-R01-UI-00516. 1969.

6. Black, R. J. and A. M. Barnes. "Effect of Earth Cover on Fly Emergence From Sanitary Landfills." *Public Works,* 89 (2):91-94, Feb. 1958.

7. Zausner, E. R. An accounting system for sanitary landfill operations. Public Health Service Publication No. 2007. Washington, U.S. Government Printing Office, 1969, 18 p.

Industrial Profiles-Food Processing Industry

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INTRODUCTION

The discussion of solid waste profiles of the food processing industry logically starts with definitions of the industry and of the solid wastes it produces. The food processing industry is that part of the business community that converts raw agricultural or fisheries commodities into finished food products. Food processing can be defined as the combination of chemical, physical, and mechanical operations that convert a raw commodity into a packaged product that has convenience of use and extended storage stability. Food processing solid wastes are the discarded solid materials resulting from the conversion of raw foods to finished products at a food processing plant.

It is useful for management planning purposes to distinguish food processing solid wastes from agricultural solid wastes and packaging solid wastes. At the same time that this distinction among various types of solid wastes is made, it must be clearly understood that the problems associated with solid waste generated in food processing are only one facet of an overall problem of greater magnitude and seriousness. Any consideration of solid food waste must also include the waste produced in the growing and harvesting of the raw crops, intact animals, whole fish, etc., transported to the food processing plants of the nation. Proposals for reducing or preventing environmental problems created by these wastes must recognize the interdependence of the raw commodity supplier, the processor, and the consumer of foods. Agricultural solid waste can be defined as those solid materials that are discarded during the growth and harvesting of food crops, poultry, and livestock. Food packaging solid wastes are the cans, bottles, caps, boxes, bags, drums, and plastic containers that result from the use of packaged foods.

Foods and Their Wastes

The food consumption patterns in the United States (Table 1) are illuminating with respect to the potential for generation of food processing solid wastes. Fluid milk and cream, red meat, potatoes, and wheat flour represent the largest fraction of the some 1,500 pounds of food consumed by each person each year. The solid wastes produced during processing of each of our food classes will be profiled.

Each segment of the food processing industry has its individual waste profile. For optimum efficiency in planning for solid waste management, it is necessary to have reliable statistics on waste quantities produced seasonally as well as on a regional and national basis. Unfortunately, the published information on food processing solid wastes is limited and fragmentary. The major reference works devoted to each segment of the food processing industry usually have only a few sentences of general comment about solid wastes.

The uninformed opinion of many scientists about the magnitude of the food processing solid waste problem is reflected in the statement "Raw food materials in general arrive in plants stripped of most of the solid waste components."[1] This statement is certainly true for many food processing operations, but it is not generally true as will be documented in this paper.

TABLE 1
Annual Per Capita Consumption of Principal Foods in the United States, 1967

Food	*Pounds consumed*
Fluid milk and cream	286
Red meats	177.5
Potatoes, white and sweet	120.0
Wheat flour	110.0
Fresh vegetables	99.6
Sugar	97.1
Fresh fruits	82.4
Processed vegetables	58.1
Processed fruits	45.9
Poultry	45.9
Eggs	41.0
Corn products	24.1
Coffee	14.7
Margarine	10.5
Cheese	9.9
Fish	9.7
Butter	5.5
Cocoa	4.2

Milk is the food material that is produced in the largest amount, some 125 billion pounds in 1967. (Table 2)

TABLE 2
Production of Dairy Products, United States, 1967

Use	*Billion of pounds*
Fluid milk and cream	59
Butter	29
Cheese	16
Ice cream and frozen desserts	13
Evaporated and dried milk	5
Miscellaneous	3

Whey, which separates during cheese making, is the major waste material in the dairy industry. About 600 million pounds of whey solids were discarded as liquid waste each year during the past 3 years. Thus, the food commodity produced in the largest amount produces only a small quantity of solid waste during processing.

The production of red meats is the second largest processed food category in the consumption pattern for the United States. The meat packaging industry has the well-deserved public image of using "everything but the squeal" from animals sacrificed in its slaughter houses. Almost all of the solid by-products from beef, calf, lamb, and hog slaughtering are utilized.

For example, in beef slaughtering, hides are trimmed and salted for dairy shipment to a tanner, or are trimmed, defleshed, and brine cured for later shipment. One stomach section may be rinsed, trimmed and scalded for sale as tripe. Intestines and windpipes may be washed, trimmed, and stripped of mucus to produce casings. Hearts, kidneys, tongue, and brains are removed and chilled for sale as edible products. The inedible portions are collected for rendering.

Other waste utilization operations in the meat packing industry produce such salable products as hog hair, coagulated beef blood, lard, glue, gelatine, and Neats-foot oil.

A major direct solid waste from beef slaughtering is paunch manure, which represents 65 to 80 pounds per head. Much of this material is flushed directly to a sanitary sewer line, but in some operations, the paunch is emptied into a screw conveyor. In California, the primary methods of disposal of paunch material from the slaughtering of 3.2 million head (1967) is by spreading these wastes on fields.[2]

The major solid waste product from meat slaughtering is in the form of sludges and skimmings from primary treatment of liquid wastes from packing house operations. The quantity of sludge varies with the degree of treatment, screen mesh size, sump pumping practice, and production activities in the packing house. Screenings from a 5-mesh screen in a packing plant slaughtering beef, calves, and hogs weighed 1.3 tons for each million gallons of wastewater treated. The screenings had a weight of 31 to 34 pounds per cu. ft. and were 81 to 85 percent water. In a primary treatment of slaughter house wastewater where a 50 percent BOD removal was achieved, sludge quantities were 8 tons per million gallons on a dry solids basis.

When it is recognized that wastewater produced has been measured at 152 to 1,810 gallons per head, and that some 130 million head of livestock are commercially slaughtered each year in the United States, the solid waste from treatment sludges and skimmings represents a substantial tonnage figure (approximately 800,000 tons).

After dairy products and red meats, the next largest category, by weight of food consumed, consists of potatoes and wheat flour. An admittedly cursory search of the food technology literature yielded no numerical information on the solid wastes from these two segments of the food processing industry.

Although producing only a small fraction of the total weight of food consumed, the fishing industry represents a segment of the food processing industry that produces substantial solid waste during processing. Of the 2.6 million tons of fresh weight of fish and shellfish caught in 1962, 273,600 tons are discarded as solid waste. The major fraction of this waste, consisting of viscera, skin, shells, and bones, is currently disposed of by dumping into waters or on land near the processing areas.

The solid waste from the canning of tuna in southern California is rendered to produce fish meal for poultry feed. This utilization practice yields a profit. The solid waste from the canning of salmon, shrimp, shad, and sturgeon is used in a pelletized form as hatchery fingerling feed in Oregon.

Long-range planners concerned with environmental pollution problems must consider the oceans of the world as part of the total disposal system available. The use of the ocean as a disposal reservoir for solid waste must be done with judgment so that no aesthetic, ecology-damaging, or public health problems occur. Of all the solid waste materials that conceivably could be candidates for ocean disposal, the material from processing of seafood must be given highest priority. These materials originate in the sea, and if they had not been removed from the sea, would normally be disposed of in the sea by reentering the natural food chain. We foresee extension of use of ocean disposal of seafood processing solid wastes in future years based on the principle of minimum ecological change.

An interesting potential utilization of clam shells as a spawning bed for oysters is under evaluation in Delaware Bay. If successful, this utilization process will promote oyster production and eliminate the current problem of odor and fly breeding during land dumping of clam shells which annually amounts to 56,000 tons in the mid-Atlantic region alone.

The industry with which we are personally most familiar is that of processed fruits and vegetables. These two processed food classes (including frozen, dehydrated, and canned fruits and vegetables) represent almost 10 percent of the weight of food consumed. The nature of the raw commodities processed leads to substantial solid waste generation. For this reason, as well as the interest this segment of the food industry has in production statistics and research, a considerable body of numerical information on solid wastes is available. Much of the information at hand, however, is based on surveys made as long as 25 years ago and does not necessarily represent the current situation.

The National Canners Association (NCA) survey programs have attempted to provide the three kinds of basic information needed for any intelligent planning of solid waste management. These are: (1) solid waste generation factors for each commodity, (2) increase factors predicted for future years, and (3) compositional data for each commodity for utilization or recycle considerations.

The NCA and the Bureau of Solid Waste Management of the U.S. Public Health Service are cooperating on a comprehensive study of solid waste management in the food processing industry. Preliminary results of the study are the basis for the estimate that 12.7 million tons of food wastes are produced, annually, by the food processing industry in the United States.

Generation Factors

The solid waste survey will collect and evaluate information from the processors of fruits, vegetables, seafoods, and specialty products covered in the Standard Industrial Classifications 2031 (canned and cured seafoods), 2032 (canned specialties), 2033 (canned fruits and vegetables), 2034 (dehydrated food products), 2036 (fresh or frozen packaged fish), and 2037 (frozen fruits and vegetables). The information is derived in two ways. A detailed questionnaire has been distributed to 1,160 food processing plants, and as of March 1, 1970, 316 responses have been received. The second part of the data collection is by site visits to food processing plants, of the 250 plants to be surveyed, 48 plant visits have been completed.

A list of solid waste generation factors for several commodities presents older data and preliminary figures from the current USPHS solid waste survey* now in progress (Table 3). There is a wide range of values for these solid waste generation factors depending on the commodity. The canning or freezing of berries, for example, produces a relatively small solid waste fraction composed largely of unsound fruit removed by sorting.

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TABLE 3
Solid Waste Generation Factors for
Certain Food Canning Commodities

Commodity	*Average ton of solid waste per raw ton received at food plant*	
	Pre-1968	*Post-1968*
Apples	0.47	0.30
Berries	0.05	na
Peaches	0.11	0.27
Pears	0.46	0.36
Asparagus	0.30	na
Beets	0.38	0.53
Corn (in husks)	0.72	0.65
Peas (field vined)	0.08	0.13
Citrus	0.53	0.50

Values for solid waste generated during the canning of four major vegetable crops are tabulated (Table 4). It is immediately apparent that the canning of corn produces a large tonnage of solid waste. Fortunately, much of this material can be used as animal feed (usually after conversion to silage).

TABLE 4
Solid Waste From Vegetable Canning, 1967

Product	*Tons canned*	*Solid waste*
Asparagus	77,200	23,150
Beets	207,000	78,600
Corn (in husks)	1,515,700	1,092,000
Peas, green (shelled)	363,000	29,000

The volume of solid waste produced during the canning of three major fruit crops is shown (Table 5). The preparation of apples for canning produces a rather substantial quantity of solid waste. In the production of apple juice, some 520 to 700 pounds of wet pomace are produced for each ton of apples pressed. In the Yakima Valley of Washington alone, there is almost 100,000 tons of solid waste produced each year from apple processing.

TABLE 5
Solid Waste Production From
Fruit Canning, 1967

Product	*Tons canned*	*Solid waste*
Apples	571,700	245,500
Peaches	706,500	77,800
Pears	259,700	119,300

When citrus fruit is processed, the waste to be disposed (peel, rag, seeds) amounts to 45 to 60 percent of the total weight of the fruit. For a medium sized plant that handles 50,000 boxes per day, there are 1,000 tons of waste to be disposed of daily. When all of the Florida citrus processing plants are using normal amounts of fruit, 100,000 to 125,000 tons of waste material must be disposed of each week. Previously, this citrus canning waste was returned to groves for fertilizer because of its perishable nature. It was disked into or covered with soil to discourage fly breeding. Now it is converted into usable cattle feed selling for $18.00 or more per ton.

Future Increase Factor

A second type of information of value for the planning of solid waste management systems is the increase factor for future years. It is possible to state with some assurance that food processing technology and food consumption patterns will change rapidly during the next 10 years. These expected changes need to be examined in some detail since they will determine both the magnitude and management of solid waste from food processing.

Food consumption trends already apparent will continue and intensify in the future. Increasing proportions of food will be purchased in a prepared or preserved form rather than as fresh food. A larger number of meals will be eaten away from the household at some type of food service operation. The demand for rapidly prepared packaged whole meals will increase, and a proliferating variety of snack foods will become available.

The food processing industry will respond to the changes in food consumption patterns by major departures from its traditional operational practices. The rate of introduction of new products or formulations in home-use package sizes will increase. Increasing proportions of products will be packaged in institutional sized containers to supply demands for remanufacture and large scale food service operations.

The changes in products packed will be reflected in production facilities that will grow larger and more highly automated. New plants will be built in areas of lower population density; those now located in urban areas will be gradually closed down as land values increase and waste disposal problems intensify.

The management of this increased solid waste load, without causing environmental pollution, is one of the challenges of the future. The relocation of some food processing operations from urban to suburban areas will partially relieve the disposal pressures. It will be necessary, however, to apply novel methods of waste management for discarded solid materials from food processing in urban locations.

The harvesting practices for crops, for example, will be a major factor in the relative proportion of agricultural or food processing wastes produced. The future will undoubtedly see a much higher proportion of sorting and pre-processing of commodities in the field to reduce the volume of solid waste generated at the site of the food processing plant. A current example of changes in field handling of a commodity is the processing of tomatoes in California. In 1968, over 4,000,000 tons of tomatoes were machine harvested with a substantial fraction going through in-field sorting and washing stations. In this way, crushed, immature, sun-burned and otherwise unusable tomatoes were kept in the growing areas where land disposal was readily accomplished. A further new experimental departure in tomato handling occurred at the trailer-mounted in-field pre-processing station operated by the USDA's Western Regional Research Laboratory. At this station, machine-harvested tomatoes were sorted, spray washed, comminuted, heated to deactivate enzymes, screened, and the juice cooled. The juice produced could be transported to a cannery for packaging or for concentration to tomato paste. The tomato pomace, consisting of skin and seeds, was kept in the field for disposal. Machine harvesting, in-field sorting, and pre-processing are trends that will continue and expand in the years ahead.

It is expected that changes in equipment and in processes used will reduce the quantity of solid waste from food canning or make it more readily utilized. Radical changes in food preparation technology (such as the "dry caustic peeling" process of potatoes, which was investigated at the USDA Laboratory in Albany, California) will produce different waste than that generated in present technology.

New varieties of food processing crops should change the nature and volume of the solid waste generated during food preservation. For example, the VF-145 tomato, which was bred for machine harvesting, is essentially coreless and thus the coring operation necessary for older varieties has largely been eliminated.

It is possible to estimate the expected increase in solid waste production from food processing by extrapolating per capita food consumption trends and combining these figures with population forecasts. The estimated solid waste production increase factors from 1967 to 1980 for several food classes are tabulated (Table 6). The factors can be used in the following way: if the solid waste from the canning of beets, for example, was 78,000 tons in 1967, it would be estimated that 78,000 × 1.52 = 118,000 tons of solid waste from beet canning would be expected in 1980. In a similar way, the expected solid waste production for all canning commodities could be estimated. The increase for solid waste from all food canning is expected to increase by 50 percent over the 1967 levels by 1980.

TABLE 6
Increase Factors for Solid Waste Production from Food Processing Production, 1980 over 1967 Levels

Food class	*Increase factor*
Vegetables, canned	1.52
Vegetables, frozen	1.95
Fruits, canned	1.47
Fruits and juices, frozen	1.77

The composition of food processing wastes and their origin relative to utilization sites dictate their disposal patterns. A survey of cannery waste management practices, conducted in 1967 by NCA, gave a disposal breakdown (Table 7), based on responses from 563 canning plants.

TABLE 7
Canning Solid Waste Disposal, 1967

Method	*Percent of canneries using*
Spread on fields	34.4
Landfill	29.1
Animal feed	30.4
Charcoal	3.9
Other	2.2

A major economic handicap in methods of utilization of food processing solid waste is the seasonal nature of the operations producing the wastes. Added to this problem is the putrescible nature of the material and the magnitude of the volume produced in a relatively short period of time. Unless other suitable organic wastes are available at other times, or unless methods of storing the raw wastes could be developed, the capacity of the processing equipment required to handle the short-time, high-volume production would be out of reason on the basis of the year-round capacity needs.

Urgently needed is research that will explore all possibilities of storing the raw wastes under conditions that will prevent nuisance conditions and allow longer-term, or year-round, utilization of the waste in economically scaled processes. Sealed, underground silos offer a fascinating possibility.

Over 60 percent of the canneries responding to the 1967 survey used land as the ultimate disposal site for solid wastes. Over one-third of the canneries spread the solid waste on the land where it was disked under to prevent insect infestation and then degraded by microorganisms. About 30 percent of the canneries disposed of waste in landfill operations where the covering solid reduced the problems caused by odors and pest breeding.

A major theme of this conference is the consideration of the reuse of solid waste as part of resource conservation. A substantial portion of food processing solid waste is utilized in some manner. The nature of the discarded food material does not permit it to be recycled in a strict sense as is possible with metals, for example. Current disposal and utilization practices for the food canning industry will be outlined and potential utilization schemes discussed in a concluding section of this report.

Composition of Processing Waste

The third major need for efficient planning for solid waste management is information on the composition of solid waste as a guide to recycle and utilization potential. There is a considerable volume of compositional information on food processing solid waste available now. Illustrative of these data are the compositional values that were obtained in a decade of effort by Edward G. Kelley and his co-workers of the USDA's Eastern Regional Research Laboratory in Pennsylvania.

Examination of the composition of typical vegetable waste indicates that most of the waste material has a high water content, 62 to 94 percent (Table 8). This fact is one of the overriding barriers to the economic use of these materials. The energy costs are very high for any dehydration process required to produce a stabilized material. The relatively high protein content of these materials in dry form makes them good candidates for a basic ingredient in animal feed mixtures.

Some isolated information is available on the composition of fruit waste. As part of a now classic study on utilization of pear cannery waste in 1948, work at the Albany, California, USDA Laboratory found the following composition: water, 85.2 percent; sugar, 7.1 percent; protein, 0.6 percent; fiber, 2.2 percent; and ash, 0.3 percent. More recently, the NCA studies on composting of fruit wastes has provided considerable compositional information.

One success story of solid waste utilization will be described as an example of the potential for other solid waste. In California, over 600,000 tons of peaches are canned each year. More than 65 percent of this tonnage is processed in plants located around San Francisco Bay, a production that generates about 60,000 tons of peach pits.

Interested canners jointly financed an operation based on the concept that peach pits ought to be excellent raw material for charcoal briquets. In an average year, from mid-July to mid-September, 500 tons per day of pits are delivered to a charcoal plant located on 20 acres of land at the south end of San Francisco Bay. Stockpiling the pits, layer on top of layer, produces two results — decomposition of adhering fruit tissue in the newest mass produces a temperature rise that inhibits insect breeding within the mass, and the confined surface area facilitates treatment with odor masking chemicals and insecticides. The charcoal briquet operation is profitable because the raw material (pits, nut shells) can be stockpiled and used on an annual basis.

Overall, this operation is successful (a second plant is now under construction at Elk Grove, California) and brightens the hope that means can be found to use other waste materials in byproducts manufacture.

Another type of solid waste not included in this discussion of food processing solid waste is the cans, bottles, caps, boxes, bags, and plastic containers that are used to package preserved foods. The collection and disposal of empty containers should be considered as part of municipal refuse management since most of the packaged foods are used in an urban environment. The food processing industry recognizes its partial responsibility in facilitating the management of solid waste derived from the packaging of its products. The industry will certainly cooperate in packaging changes that would ameliorate disposal problems. The Glass Containers Manufacturers Institute has devoted considerable effort to problems associated with glass containers in solid waste and their position has been summarized.[3]

The food canning industry must emphasize the utility of the sanitary, double-seam can in providing product integrity. This container, of which some 24 billion were used in 1969 for canned foods, has a remarkable record of success in maintaining food in a wholesome condition even with the higher level of vibration and shock that containers receive in modern automated handling systems. The ferrous metal can, in which the

TABLE 8
Composition of Typical Vegetable Solid Wastes

Vegetable tissue fraction	Moisture (%)	Proportion of whole top: Fresh basis (%)	Proportion of whole top: Dry basis (%)	Protein (%)	Chemical analyses (moisture-free basis): Crude fiber (%)	Chemical analyses (moisture-free basis): Ether extract (%)	Chemical analyses (moisture-free basis): Carotene (ppm)	Chemical analyses (moisture-free basis): Riboflavin (ppm)
Beet:								
Leaf	90.4	52.6	54.2	27.3	6.0	6.2	568	21.5
Stem	91.0	47.4	45.0	13.6	14.7	1.7	48	7.4
Broccoli:								
Leaf	81.5	36.4	53.7	35.9	7.6	8.5	803	25.6
Petiole and stem	91.0	63.6	46.3	19.0	16.5	3.3	81	8.5
Cabbage, leaf	-	-	-	22.4	8.2	4.7	295	9.9
Carrot:								
Leaf	79.0	51.2	65.1	27.9	10.1	5.6	295	15.7
Stem	88.1	48.8	34.9	11.1	19.3	5.4	41	8.1
Cauliflower:								
Leaf	-	-	-	26.6	9.5	4.1	185	23.2
Petiole	-	-	-	17.1	17.3	-	28	9.2
Celery:								
Leaf	87.0	-	-	27.2	3.5	6.9	352	18.4
Stalk	94.0	-	-	12.6	14.3	3.1	11	5.7
Collard:								
Leaf	-	-	-	27.3	6.8	5.3	251	15.8
Petiole	-	-	-	14.8	9.8	-	28	-
Corn, sweet, leaf	-	-	-	17.1	26.6	5.5	578	5.5
Kale:								
Leaf	77.3	57.5	63.3	29.4	7.6	5.8	340	21.0
Petiole and stem	82.3	42.5	36.7	16.2	10.0	4.2	21	8.0
Lima:								
Bean	61.6	20.8	28.1	23.9	6.0	3.7	3	2.4
Leaf	67.7	15.8	18.0	19.4	10.5	6.4	465	12.4
Pod	77.1	25.8	20.9	10.0	37.8	3.0	14	3.7
Stem	74.3	36.9	33.5	9.2	40.1	2.2	36	3.9
Parsnip:								
Leaf	-	-	-	22.9	8.0	5.0	232	11.9
Stem	-	-	-	6.0	17.2	-	4	4.3
Pea:								
Leaf	65.7	12.3	14.1	21.7	14.4	5.8	346	26.2
Pea	80.1	22.4	19.9	28.8	9.2	1.7	4	7.8
Pod	84.0	35.5	25.2	14.1	18.4	1.2	23	7.8
Stem	67.4	29.9	41.0	11.0	39.2	2.3	47	9.6
Rutabaga:								
Leaf	82.2	36.1	51.4	31.5	6.3	6.5	257	20.9
Stem	90.5	63.6	48.4	18.5	14.9	-	13	8.5
Turnip:								
Leaf	87.3	46.8	61.9	30.9	7.5	4.4	473	20.3
Stem	93.1	53.2	38.2	18.0	10.3	-	54	11.6
Spinach:								
Leaf	90.4	45.1	54.7	32.0	6.8	4.1	314	14.6
Stem	93.5	55.0	45.3	22.5	9.3	-	120	8.5

major portion of canned foods are packed, has advantages in solid waste management because of possibilities of magnetic sorting, ready oxidation, and reuse potential as blast furnace feed. Cans made from aluminum present a special resistance to oxidation. It has been estimated that 3 billion aluminum cans for beer and soft drinks were used in 1969. This represents 10 percent of the production of these products. It has been estimated by spokesmen of the aluminum metal suppliers that use of aluminum cans will triple by 1974. A relatively new use of aluminum cans is for easy opening containers for snacks or "brown-bag" lunches. These products are very popular, in the initial marketing period, for puddings and fruits as salads or desserts, leading to a predicted major expansion of sales and concomitant increase in wasted aluminum containers. If the discarded aluminum cans can be segregated readily from other refuse, the recycle potential is high.

Composting

For many canneries in urban locations, the availability of municipally operated systems for disposal of solid waste may be restricted for technological or economic reasons. These canneries may find composting of solid waste the most efficient method of disposal. Composting is the process by which organic material is converted to a stabilized solid by degradation of the more labile part of the material with thermophilic microorganisms that are encouraged by control of aeration, moisture, temperature, and nutrient addition.

Personnel at the NCA Research Laboratories have studied the use of composting for the management of canning solid wastes during the past several years. We appreciate very much the support we have received from the Public Health Service in this research.

Composting has been demonstrated to be a feasible method of stabilizing and reducing the volume of segregated municipal refuse in a number of U.S. and foreign installations. The limiting consideration in composting has always been the ultimate disposal of the final composted material. The market for compost product as a soil conditioner has never been large enough to utilize the potential production. The utility of composting as a solid waste disposal method has recently been analyzed in a particularly lucid way by Professor Samuel A. Hart of the University of California, Davis, who reached the conclusion stated above.[4] We agree with his analysis of the present situation, but believe that the demand for composted food processing wastes will increase as more marginal agricultural lands are brought into production. The increasing food production needed in the next decades will require that land now considered unusable be modified by soil amendments to become productive. Among the better potential soil amendments is the material produced by the composting of food processing solid waste. Humus or humic substances, derived from compost, are necessary to provide good soil structure. The compost also provides nutrients necessary for good crop growth when chemical fertilizers only are added to irrigation water. The combination of a number of agricultural and food processing solid wastes as compost feed is the most attractive for an amendment material.

The NCA studies on composting solid waste from canning started with small-scale feasibility studies and have progressed to field studies using mechanized waste addition and windrow turning and forming. The early studies developed the basic conditions for the efficient composting of fruit-canning wastes. One of the first requirements was for a blending material to absorb the excess water of comminuted fruit waste in order to obtain optimum moisture levels in the compost mass. Rice hulls and sawdust, both of which are solid waste materials, proved to be most satisfactory for this purpose. The fruit waste solids, subjected to composting, were reduced to carbon dioxide, water, and ammonia; little residue was left to increase the bulk of the compost mass. The heat generated during the bacterial degradation drives much of the water out of the compost mass. The resulting composted material could be used as a moisture-absorbing material and recycled through an entire season as the fresh waste was periodically added.

In the most recent equipment development stage, the composting was conducted in wooden bulkheads on an asphalt surface. The bulkheads contained the compost mass in a windrow 40 feet long by 9 feet in width and 4 to 6 feet in depth. Perforated copper pipes were recessed in the floor of the windrow to provide forced aeration. A machine was designed and constructed to automatically apply and mix the waste material with the compost mass. The unit (called the Composter — mention of a commercial product does not necessarily imply endorsement by the U.S. Public Health Service) was equipped with two sets of traveling buckets so that material could be handled in either direction of movement. The entire unit was suspended on two axles mounted through boat trailer wheels that travel on 3-inch steel pipes located on top of the walls containing the compost windrow. The bucket and traversing drive mechanisms were controlled by reversing switches mounted on a control panel attached to the framework. As the turning mechanism moved down the length of the windrow, the compost in the path of the machine was picked up and redeposited behind the machine; mixing and aeration were accomplished by picking up and dropping the compost. Maintenance of aerobic conditions within the compost mass was ensured by the continuous use of forced aeration.

During 1966, the composting of ground fruit canning solid waste was conducted continuously for 26 days. Initially 5,000 pounds of waste were added to the windrow containing 40 cu. yds. of rice hulls. The addition of waste was continued until a total of 68,000 pounds had been added at an average rate of 87 pounds per day per cu. yd. of rice hulls. A windrow area of 360 feet would accommodate 2,600 pounds of waste per day.

As an example of the utilization of composting for stabilization on a commercial scale, a large plant canning pears would produce about 100 tons of solid waste per day. This quantity of waste would require a windrow area of approximately 30,000 feet. The holding sump, dump truck ramp, grinding and pumping installation, and buffer zone would require an additional 50,000 sq. ft. Therefore, a 2-acre plot of ground would accommodate the composting needs of a large fruit canning plant. At the end of the season, the final compost mass of approximately 5,000 cu. yds could be held for reuse in a subsequent season.

There is still one serious problem that must be resolved before food processing waste compost could be applied to agricultural lands; this is the question of contamination from pesticide residues. The solid waste material that would be composted is that portion of the raw product that has the highest pesticide residue content.

During the past 2 years, we have been studying the degradation of insecticides during composting. The results of these studies show that the organophosphate and carbonate classes of pesticides would be rapidly and completely degraded during composting. The chlorinated hydrocarbon insecticides would be only partially degraded during continuous thermophilic composting as now conducted. Presently, we are investigating the ability of specific microorganisms to degrade the resistant insecticides with the expectation that conditions of optimum growth of these species during composting would result in complete degradation. An insecticide residue-free compost material would have obvious advantages as a soil improvement agent, especially if forage crops for dairy herds were grown on these upgraded marginal lands.

In testifying before the Senate Subcommittee on Air and Water Pollution on February 26, 1970, Walter Mercer gave the present NCA legislative policy on food-processing solid waste management. He stated that the canning industry believes that appropriate Federal, regional, and State agencies should receive whatever authorization and assistance are necessary for developing and disseminating the information so urgently needed.

REFERENCES

1. "The Food Industry and Pollution," *Food Technology*, February, 1970.

2. Cornelius, James. *California Vector Views* 16(5), 1969.

3. *Environmental Science and Technology*, 3(1), pp. 17-18., 1969.

4. Hart, Samuel A. University of California, USPHS Contract PH 86-67-13.

Rubber Industry

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INTRODUCTION

The rubber industry, as defined in contract PH-86-68-208 includes all manufacturers in Standard Industrial Classification 301, 302, 303, and 306. These are the manufacturers of finished rubber products (Table 1). Not included are the manufacturers of synthetic rubber polymers classified under SIC 282.

TABLE 1
Products Studied

SIC	*Product*
301	Tires and Tubes
302	Footwear
303	Reclaimed Rubber
306	Rubber Products, N.E.C.
	Not Included
282	Synthetic Rubber

The study is based on the year 1968. It would have been more desirable to use 1967, as this is the year studied by the Census of Manufacturers. However, in 1967, the rubber products industry was on strike for over three months, and data taken from that year would not have been representative.

We studied 75 corporations and over 100 manufacturing sites. The technique employed was to visit our own UNIROYAL operations in detail as a first step. This gave us a base to work from and made us aware of all the potential areas of solid waste generation. All of our data were gathered by personal interview and inspection of waste records of the cooperating corporations. Cooperation was very good, as less than 10 percent of the companies contacted refused to participate in the survey.

As stated, we visited 75 companies. One might ask if this is representative of the rubber products manufacturing industry. Well, there are over 1,500 corporations and 2,000 factories. We visited 5 percent of the companies (Table 2).

TABLE 2
Survey Participants

Total Companies	1,500
Total Plants	2,000
Companies Visited	75
Plants Visited	100
Percentage Coverage	5

However, this 5 percent of the companies accounted for over 50 percent of the production of the rubber products industry (Table 3).

With the exception of California, manufacturing is located predominently in the central and northeast states. Ohio is the leading producer with 20.0 percent; followed by California with

6.7 percent; Massachusetts, 6.4 percent; Pennsylvania, 5.7 percent; and Indiana and Michigan with 5.6 percent each.

Tire and Tire Products

The largest rubber product category is tires and tire products, which account for 68 percent of the production of finished rubber products. Six major companies account for over 85 percent of the tire production in the United States. Inner tubes, mostly for trucks, and other tire related products are usually produced in the tire plants.

Passenger car tires account for 80 percent, by number, of all tires produced (Figure 2). Truck and bus tires make up the bulk of the remaining 20 percent. Tire production is increasing about 3 to 5 percent per year. Our projection for 1973 of 240 million tires has taken into account the longer mileage expected from the new bias-belted tire.

Passenger car tires account for only 65 percent by weight of all tires manufactured (Figure 3). The weight of solid waste generated is plotted on the right side of Figure 3. This shows that for every million pounds of tires produced, there is slightly more than 50,000 pounds of solid waste generated. The average for the industry as a whole is 106,000 pounds of solid waste per million pounds of finished product.

TABLE 3
Percent of Rubber Products
Industry Surveyed

Product	*% of Total Industry*	*Manufacturing Capacity of % Surveyed*	*Effective % of Industry Surveyed*
Tires	68.0	67	46.0
Footwear	4.0	40	1.6
Belt	2.5	50	1.3
Hose	3.1	40	1.2
Foam and Sponge	5.5	9	0.5
Mechanical Goods	16.9	25	4.2

Paper, cardboard, and wood waste are packaging material from incoming raw materials such as synthetic and natural rubber, carbon black, and chemicals used in the fabrication of the rubber product.

Rubber compound is the combination of elastomers, oils, pigments, and other chemicals, and is usually in the unvulcanized state. This is true process waste, whereas the paper, cardboard, and wood are not.

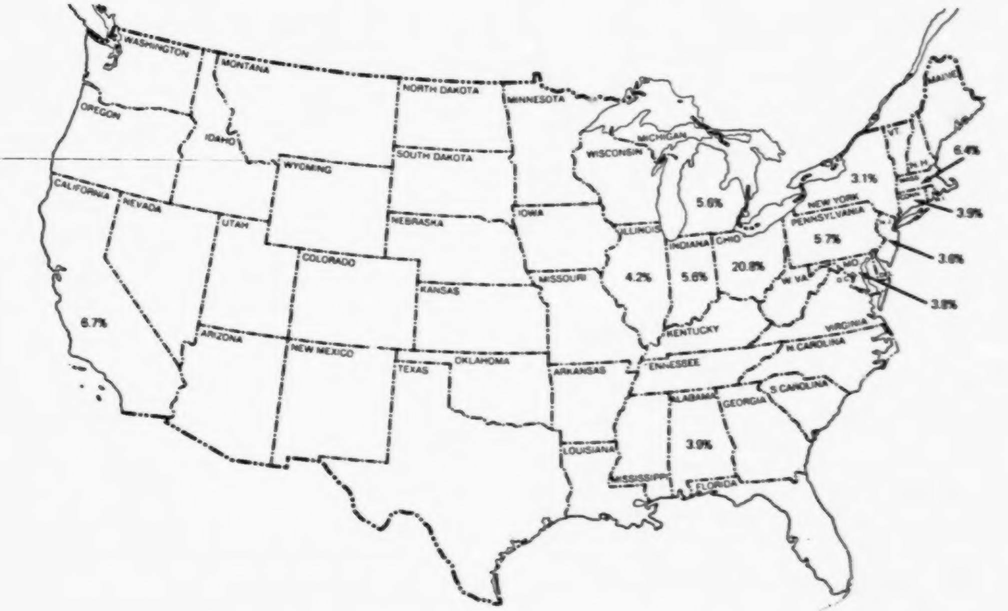

WASHINGTON
MONTANA
NORTH DAKOTA
MINNESOTA
MAINE
OREGON
IDAHO
SOUTH DAKOTA
WISCONSIN
MICHIGAN
VT
N.H.
6.4%
WYOMING
3.1%
CALIFORNIA
NEVADA
5.6%
NEW YORK
3.9%
UTAH
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
5.7%
COLORADO
3.6%
KANSAS
MISSOURI
4.2%
5.6%
20.8%
W. VA.
MD
D.C.
3.8%
6.7%
KENTUCKY
VIRGINIA
ARIZONA
NEW MEXICO
OKLAHOMA
N. CAROLINA
TEXAS
ARKANSAS
TENNESSEE
S. CAROLINA
ALABAMA
GEORGIA
3.9%
LOUISIANA
MISSISSIPPI
FLORIDA

Figure 1: Twelve Major Fabricated Rubber Products Manufacturing States Based on Value of Goods Shipped

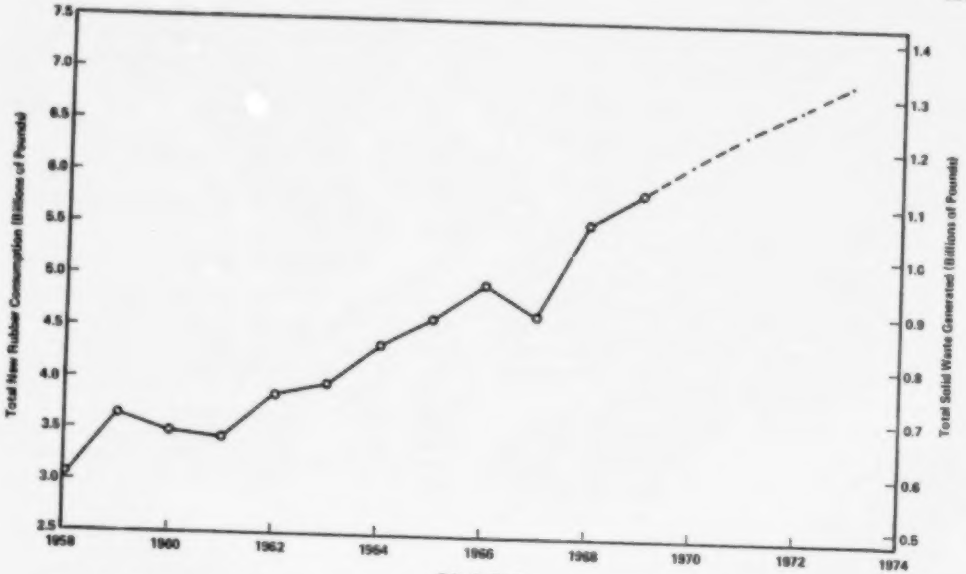


Figure 2: Total New Rubber Consumption and Solid Waste Generation in the Fabricated Rubber Products Industry

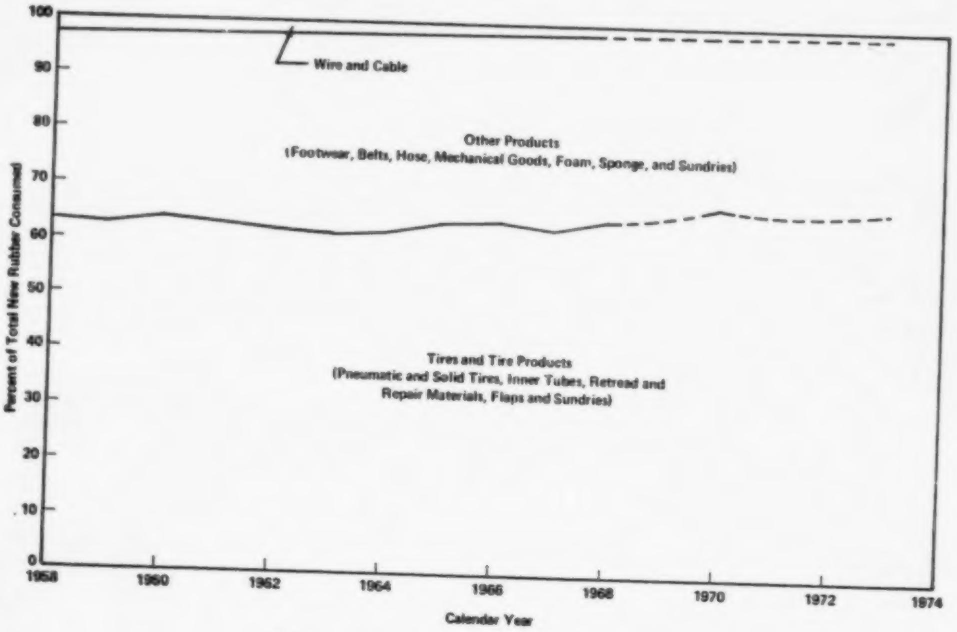


Figure 3: Percent of Total New Rubber Consumed

TABLE 4
Composition of Waste From Tire Manufacturing

Type of Waste	*lbs./Million lbs. of Tires*
Paper, Cardboard, Wood	13,400
Rubber Compound	11,900
Textile	5,900
Metal	9,700
Other	14,000
Total	54,900

The "other" category includes floor sweepings, cafeteria wastes, office waste, and polyethylene separators used in the production process. The separators are usually used more than once and are placed between layers of rubber compound to keep them from sticking to each other.

The total waste per million pounds of tires, which is actually about 40,000 tires, was the lowest waste ratio found in the entire rubber products industry. Note that rubber compound is only 1 percent of the waste generated per million pounds of tires produced.

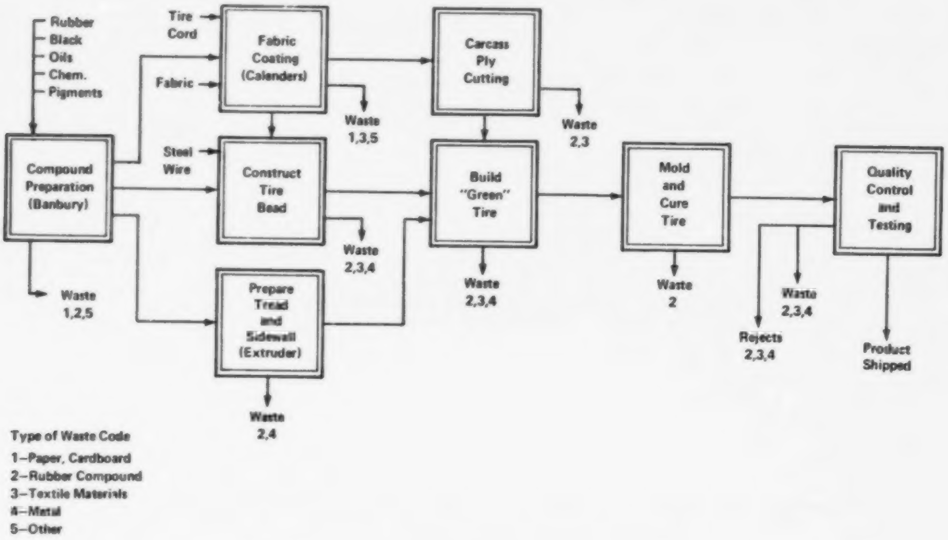
The processing steps for all products was traced. Because tires are fairly typical, their manufacturing process serves as a good illustration (Figure 4). At each step in the manufacture, the type of waste produced is noted. Paper, cardboard, and wood wastes are generated very early in the production cycle and would be easy to segregate. They are *not* segregated however; all wastes are placed in common receptacles and are then taken to dumps or landfill sites.

At the last step before a tire is shipped, there is some destructive testing. This material is also classified under waste. Rejects are those tires falling outside specification whose faults cannot be corrected. These are destroyed by cutting and then disposed of.

Rubber Footwear

Rubber footwear production, which represents 4 percent of total rubber product production, has been on the decline for several years now because of lower priced foreign imports (Figure 5). Each million pounds of footwear produced represents approximately 250 million pairs of rubber footwear. There are about 200,000 pounds of solid waste generated for every million pounds of footwear produced. (The lower line on Figure 5 is read at the right.)

Large amounts of rubber compound and textile scrap are noted when the waste is broken down by type (Table 5). This is primarily because of the extensive amount of trim scrap generated by an operation, much like cookie cutting. In rubber footwear production, however, most of this scrap is not reusable.



Rubber
Black
Oils
Chem.
Pigments
Tire Cord
Fabric
Fabric Coating (Calenders)
Waste 1,3,5
Carcass Ply Cutting
Waste 2,3
Steel Wire
Compound Preparation (Banbury)
Construct Tire Bead
Waste 2,3,4
Build "Green" Tire
Waste 2,3,4
Mold and Cure Tire
Waste 2
Quality Control and Testing
Waste 2,3,4
Rejects 2,3,4
Product Shipped
Waste 1,2,5
Prepare Tread and Sidewall (Extruder)
Waste 2,4
Type of Waste Code
1–Paper, Cardboard
2–Rubber Compound
3–Textile Materials
4–Metal
5–Other

Figure 4: Schematic Diagram of Tire Manufacturing Process

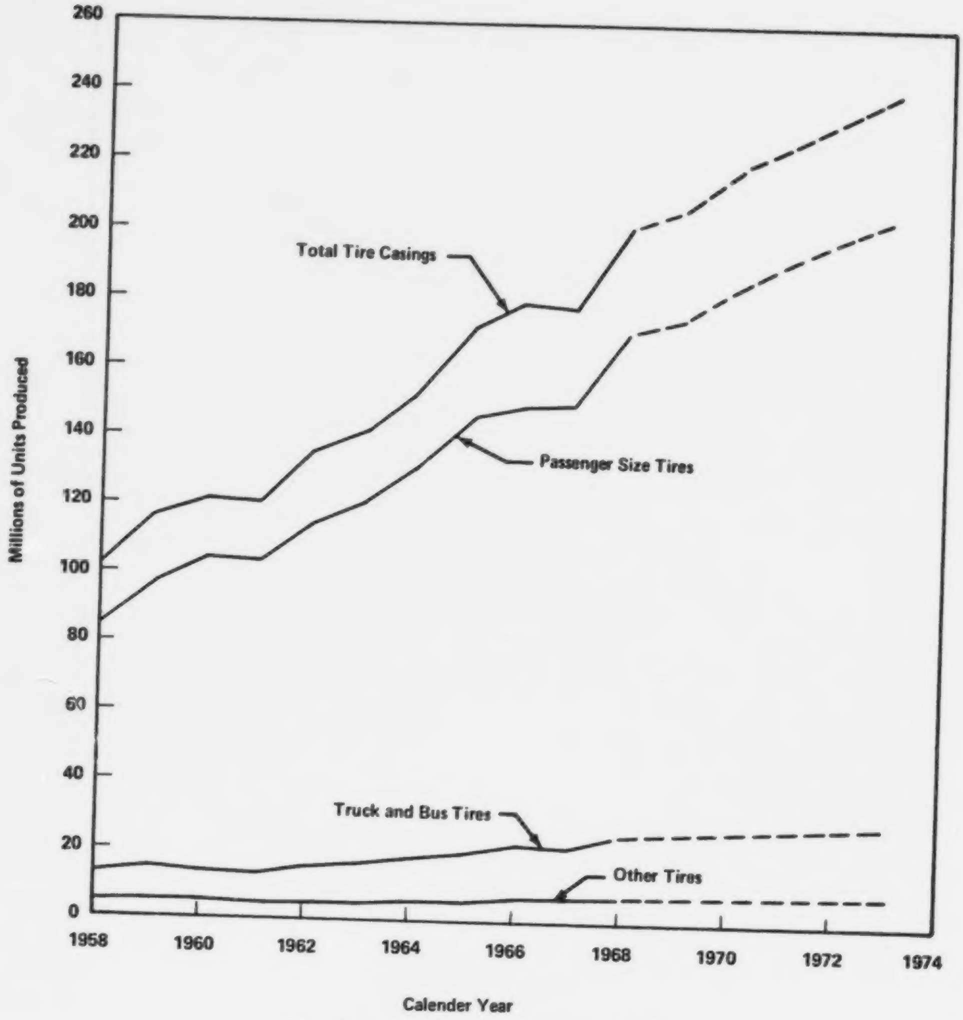


Figure 5: Number of Automotive Tires Produced

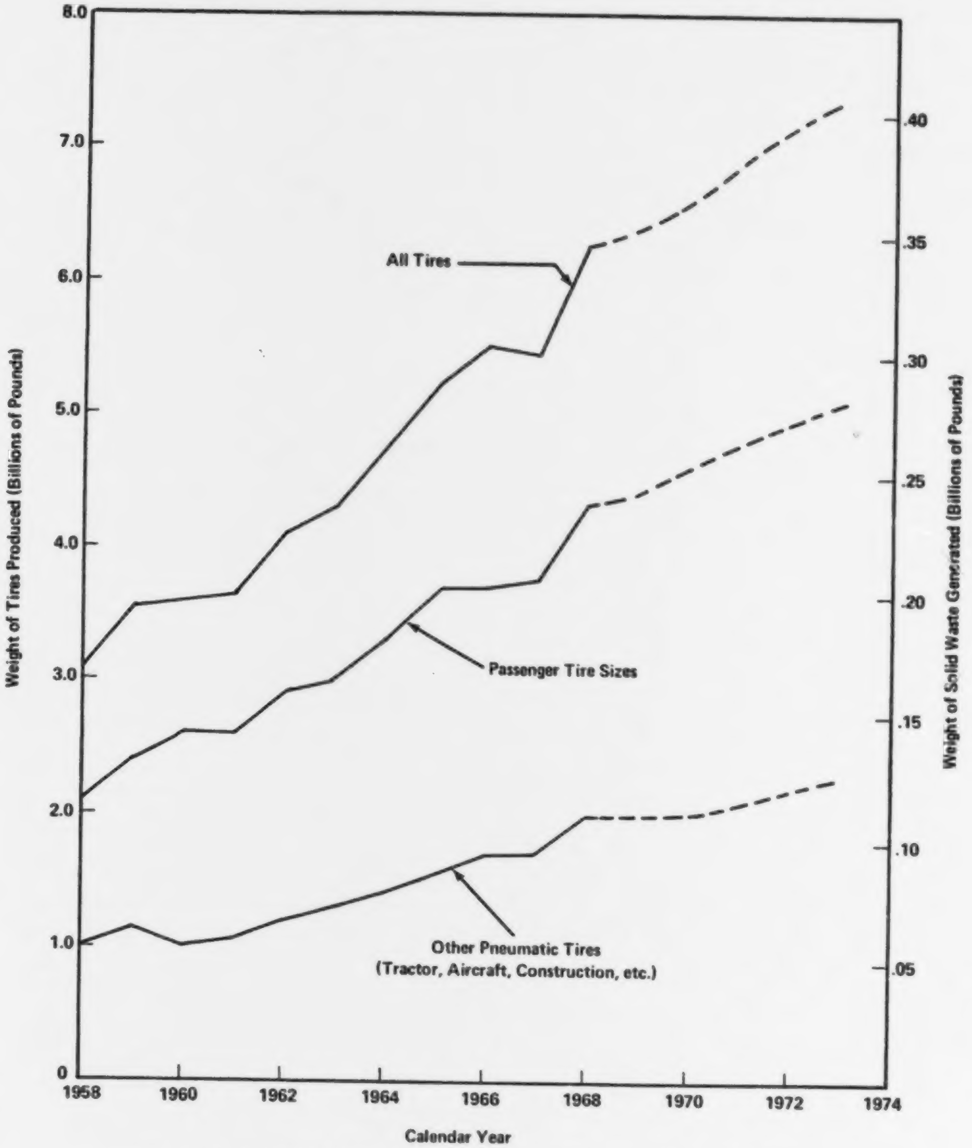


Figure 6: Product Weight of Tires Produced and Solid Waste Generated in Their Production

TABLE 5
Composition of Waste from
Footwear Manufacturing

Type of Waste	*lbs./Million lbs. of Footwear*
Paper, Cardboard, Wood	17,000
Rubber Compound	90,000
Textile	66,000
Metal	1,000
Other	35,000
Total	209,000

Rubber Belt

Rubber belt accounts for 2.5 percent of the production of the rubber products industry. Production is growing about 10 percent per year and is expected to continue for the next 3 to 4 years (Figure 6). Tires and footwear are purchased directly by the consumer, whereas rubber belt is used mainly for industrial applications. Consumer applications for belts as part of larger machines are numerous, but the weight of the individual belts is small, e.g. automobile V-belts weigh about 8 ounces. Solid waste generation is about 13 percent of production (as shown on the right side of Figure 6).

The breakdown by type of waste for belts is just about average for the rubber products industry (Table 6). Belt production is similar to tires and footwear in that a large number of stock items are produced. There is also a fair amount of custom manufacture that tends to increase the solid waste percentage because of very short production runs. A good deal of the waste is generated during start-up and clean-out operations.

TABLE 6
Composition of Waste from
Belt Manufacturing

Type of Waste	*lbs./Million lbs. of Belt*
Paper, Cardboard, Wood	27,300
Rubber Compound	41,000
Textile	25,200
Metal	2,300
Other	30,200
Total	126,000

Rubber Hose

Rubber hose accounts for 3.1 percent of the rubber products manufactured. Production is increasing about 8 percent per year (Figure 7). Most hose is used industrially. Rubber hose utilized by the consumer is garden hose or washing machine hose (large in footage, but low in weight per unit length). Solid waste generated by hose manufacture amounts to 16.5 percent of production (Table 7).

Most hose is made of an inner and outer tube reinforced with a textile or a metal. Hose is usually made in short lengths (1,000 feet). The high amount of waste is due to constant start-up and shut-down of equipment. Most hose production facilities were found to be merely job shops with only a limited number of standard items. This differs markedly from tires and footwear where

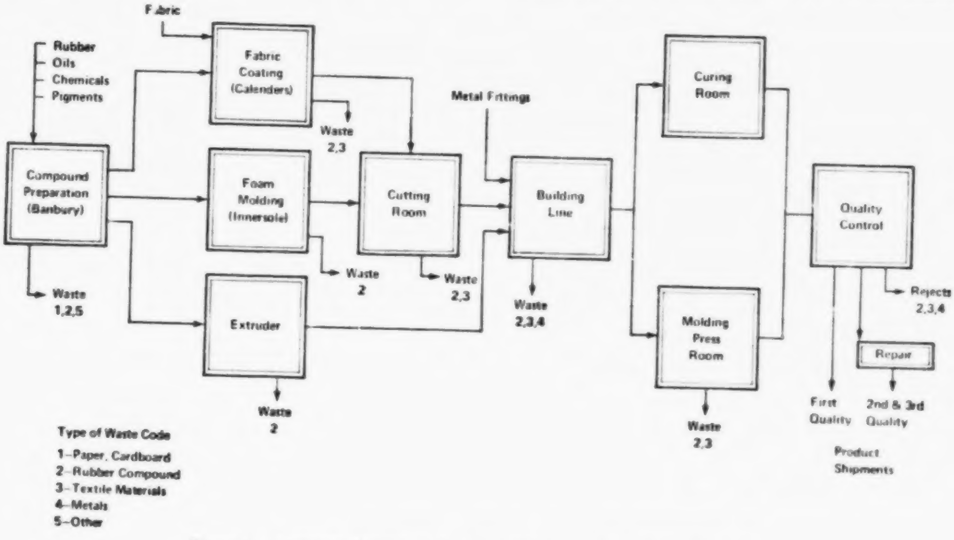

Fabric
Rubber
Oils
Chemicals
Pigments
Fabric Coating (Calenders)
Waste 2,3
Metal Fittings
Curing Room
Compound Preparation (Banbury)
Foam Molding (Innersole)
Cutting Room
Building Line
Quality Control
Waste 1,2,5
Waste 2
Waste 2,3
Waste 2,3,4
Rejects 2,3,4
Extruder
Molding Press Room
Repair
Waste 2
First Quality
2nd & 3rd Quality
Waste 2,3
Product Shipments
Type of Waste Code
1–Paper, Cardboard
2–Rubber Compound
3–Textile Materials
4–Metals
5–Other

Figure 7. Schematic Diagram of Canvas and Waterproof Footwear Processes

TABLE 7
Composition of Waste from Hose Manufacturing

Type of Waste	*lbs./Million lbs. of Hose*
Paper, Cardboard, Wood	33,300
Rubber Compound	54,700
Textile	18,300
Metal	10,200
Other	49,300
Total	165,800

TABLE 8
Composition of Waste from Sponge Manufacturing

Type of Waste	*lbs./Million lbs. of Sponge*
Paper, Cardboard, Wood	16,000
Rubber Compound	90,000
Textile	200
Other	27,000
Total	133,200

large numbers of stock items are produced for general sale.

Rubber Sponge

Rubber sponge accounts for 5.5 percent of the rubber products manufactured. Production of foam and sponge is increasing about 6 percent per year (Figure 8). Examples of rubber sponge and foam products are mattresses, pillows, and energy absorbing foam used in automobiles. Rubber foam is also used under the new synthetic playing fields. Waste in this category is 13 percent of production (Table 8).

Rubber compound waste is high because the material is cured and foamed simultaneously. If poor quality foam is produced, the manufacturers cannot salvage it or reuse the material. He may, however, be able to sell it to low quality furniture manufacturers. Much foam scrap is also sold for stuffed toys and pillows.

Mechanical Rubber Goods

Mechanical rubber goods are those products that do not fall into any of the other categories, e.g. bumpers, jar seals, heels and soles, and drug and medical sundries. This category makes up 17 percent of the rubber products industry. The product mix here is very complex and most of the 1,500 corporations fall into this general category in some way.

This product category again falls into the job shop category, and products are usually made in small quantities. As stated previously, this usually

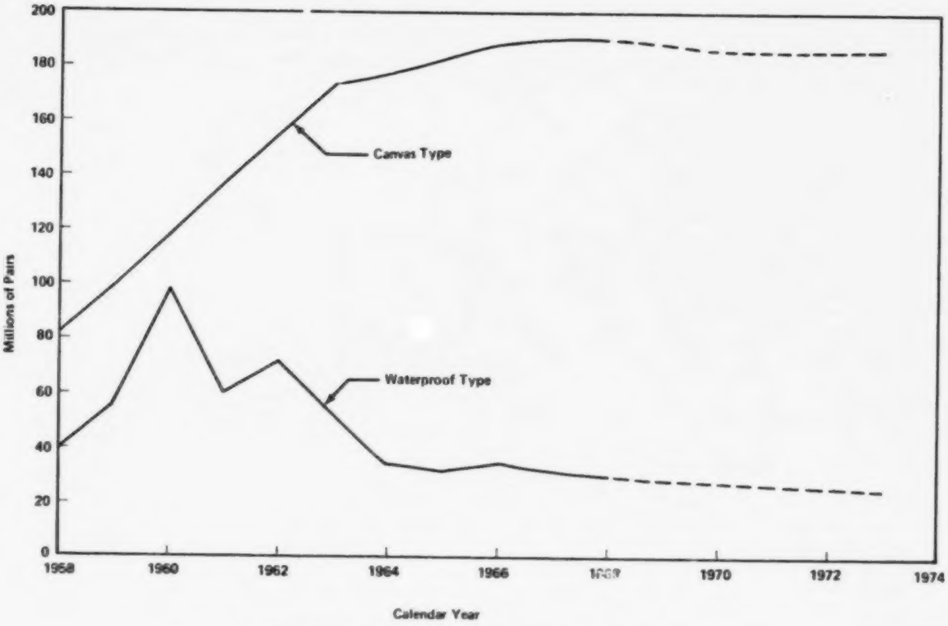


Figure 8: Production of Rubber Footwear by Number

leads to a high level of solid waste generation, about 25 percent of production (Table 9). All types of solid waste are generated in amounts exceeding the industry average.

TABLE 9
Composition of Waste From Mechanical Rubber Goods Manufacturing

Type of Waste	*lbs./Million lbs. Mechanical Goods*
Paper, Cardboard, Wood	43,700
Rubber Compound	93,800
Textile	28.500
Metal	14,200
Other	68.000
Total	248,200

To summarize the whole rubber industry, tires account for 68 percent of production, but only 41 percent of the waste; footwear accounts for 4 percent of production and 10 percent of the waste; belt, for 2.5 percent of production and 3.2 percent of the waste; hose, for 3.1 percent of production and 5.8 percent of the waste; foam and sponge, for 5.5 percent of production and 8 percent of the waste; and mechanical goods, for 17 percent of production and 37 percent of the waste (Table 10). The industry's waste level is 10.5 percent of production.

Note that only 35 percent of this waste is rubber compound. The rest, with the exception of metal, is easily incinerated. Because solid waste generally is not segregated, however, it all winds up in landfill sites. This dumping of easily combustible materials is a sad misuse of our dumps and landfills, which are growing scarce.

Synthetic Rubber

Though the production of synthetic rubber is not the subject of this study, there is a very direct relation between synthetic rubber production and rubber products manufacture. The exact amount of rubber products manufactured in any given year is quite difficult to determine. Synthetic rubber production and consumption, however, is recorded quite accurately by government studies and the Rubber Manufacturers Association. Presently, solid waste in the rubber product industry is 18 percent of the total synthetic rubber consumed. It is not expected to change in the next few years.

Reclaim Rubber

The reclaim rubber industry, although classified under an SIC code that makes it part of the rubber products industry, is more like the synthetic rubber industry in that it supplies raw material to the rubber products industry. Thus, the reclaim rubber industry is treated separately.

The total pounds of reclaimed rubber produced in the next 3 to 4 years are expected to remain constant; however, the total pounds of virgin polymer used will increase 3 to 5 percent per year. This means that use of reclaim rubber in rubber products is actually diminishing. The very real possibility exists that some day the demand for reclaimed rubber will diminish to the point that this product will cease to be. Most reclaiming operations are presently operating with very little profit or a negative one.

The reclaim rubber industry utilized about 580 million pounds of waste rubber in 1968. Over 80 percent of this was old tires. The output of reclaim rubber in 1968 was also approximately 580 million pounds. Though this appears to be 100 percent conversion, it is not. Bead wire and tire cord are discarded and other chemicals and fillers are added in their place.

The waste generated by the reclaim industry is shown in Table 11. The textile-rubber mix is 97 percent textile, and presently there is no use for

TABLE 10
Solid Waste Generated by the Fabricated Rubber Products Industry, 1968, (millions of pounds)

Type of Waste	*Type of Rubber Product*						
	Tires and Tire Products	*Foot-wear*	*Belts*	*Hose*	*Foam and Sponge*	*Mech. Goods*	*Total*
Paper, cardboard, and wood	100.5	8.5	6.8	11.7	9.6	65.5	202.6
Rubber Compound	89.3	45.0	10.2	19.2	54.0	140.7	358.4
Textile Materials	44.2	33.0	6.3	6.3	0.1	42.8	132.7
Metals	72.7	00.5	0.6	3.6	-	21.3	98.7
Other Materials	105.2	17.5	7.6	17.2	16.2	102.0	265.7
Total Wastes	411.9	104.5	31.5	58.0	79.9	372.3	1,058.1

this material. It offers possibilities as an insulating or building products material. The waste generated by reclaim rubber manufacture is 13 percent of the finished product output, about the same as the rest of the rubber products industry.

TABLE 11
Composition of Waste From
Reclaim Rubber Manufacturing

Type of Waste	*Total Waste, Million lbs.*
Paper, Cardboard, Wood	8.0
Rubber	11.6
Textile-Rubber Mix	37.1
Metals	13.2
Other	5.3
Total	75.2

Consumed Rubber

Tires are the major item of consumer rubber products and pose the biggest headache as far as disposal is concerned. They are not easily incinerated and make poor landfill. As one might expect, tires are found where automobiles are registered. Six main metropolitan areas account for over 30 percent of all used tires. They are New York with 10 percent; Los Angeles, 6 percent; Boston, 5 percent; Chicago, 4 percent; and Cleveland and Pittsburgh, 3.3 percent each. Over 35 percent of the used tires are found east of Cleveland, Ohio. Our finished report will show used tire disposition by state and metropolitan areas.

The disposition of used tires in 1968 and the predicted disposition in 1974 is given in Table 12. Sooner or later all tires become a disposal problem whether they are retreated or reclaimed. Retread tires wear out and usually are not retreaded a second time. The reclaimed material becomes part of another tire which sooner or later is discarded.

TABLE 12
Tire Disposition (millions of tires)

Type	*1968*	*1974*
Tires Discarded		
Passenger	121	158
Truck and Bus	15	22
Tires Reclaimed		
Passenger	16	15
Truck and Bus	-	-
Tires Retreaded		
Passenger	36	41
Truck and Bus	10	11

Notice that the number of tires reclaimed is predicted to decrease even though the weight of reclaimed rubber produced will remain the same.

The explanation is simple enough. Each tire produced today that will be reclaimed 3 to 5 years from now weighs more than the tires produced a few years ago, which are being reclaimed today.

CONCLUSIONS

After studying the rubber products industry and coming up with reams of data on waste types, amounts, and distribution, we also discerned that rubber industry management is aware of the importance of waste disposal. After their best efforts to reduce the volume of their waste, however, they feel they have neither time, talent, nor resources to devote to the problem. They do not consider present solid waste disposal means acceptable, so they simply turn over their solid waste to a contractor at a price.

The greatest need is for an economical incineration system that will perform within firm long-range and reasonable anti-pollution standards. Only a limited number of rubber products facilities would be large enough to maintain their own incinerator, but in some locations groups of these and related industries could maintain one. For isolated manufacturers, cooperation with municipal disposal operations would be in order. The two important requirements for incinerators are the following:

(1) Early establishment of practical firm long-term standards for performance of incinerators with respect to pollution control.

(2) Support and encouragement of research and design development on proper incinerators especially for operation on solid rubber wastes. If such incinerators could be further developed to produce process steam, they would be even more attractive, as rubber fabricators are large users of low-pressure steam and this would offer some return on investment.

Certainly the long-run reuse or recycle is the best answer to the problem. Present examples of this are the following:

(1) Pyrolysis of old tires to regenerate basic chemicals and oils. This work has been started by Firestone Rubber Company in cooperation with the Bureau of Mines.

(2) If feasible, use of ground tires as a filler in asphalt paving materials at a level of 5 percent would utilize all the old tires generated in the United States this year.

These ideas and experiments are just the beginning of potential reuse and recycle procedures that will someday alleviate our solid waste problem and also slow the pace at which we are exhausting our raw material resources.

Disposal of Solid Polymer Wastes by Primary Producers and Fabricators*

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INTRODUCTION

This study deals exclusively with the industrial, or "pre-consumer," aspect of the solid polymer waste problem. We have explored the nature and extent of that problem in the United States for that segment of the plastics industry representing the largest product tonnage, namely the segment dealing in the production and fabrication of the principal thermoplastics. We have gathered technical and economic information on polymer waste disposal methods in actual use, and have evaluated alternative approaches to solid polymer waste disposal.

Description of the Plastics Industry

The plastics industry is composed of three major sectors, with some overlap (Figure 1).

- producers of the basic resins
- processors who convert the resin into some standard shape or form
- fabricators who fashion the final product from the resin directly, or from a processed form. (In the latter case, the fabricator is often called a "converter.")

The resin producer usually begins with the basic raw material (such as petroleum or natural gas), manufactures the monomer, and ends up with the resin. Some producers begin with purchased monomer; others continue beyond the resin stage into processing and fabrication. The resin producer today characteristically has an operation requiring a large investment, an economic and adequate source of raw material, an advanced technical ability, an extensive research and development program, and an aggressive sales force.

Plastics processors and fabricators concentrate on custom operations (made-to-order parts), proprietary operations (using specially designed or developed toolings), or captive operations (utilizing fabricated parts in other company functions to make finished products). In the United States alone, there are estimated to be close to 2,500 plastics processors and 4,000 fabricators. Most of these relatively small firms specialize in particular resins, fabricated shapes, or finished products. They generally do not have the research facilities or resources to develop new fabrication techniques, and thus are often dependent on the resin producers, who commonly expend considerable effort on applications research.

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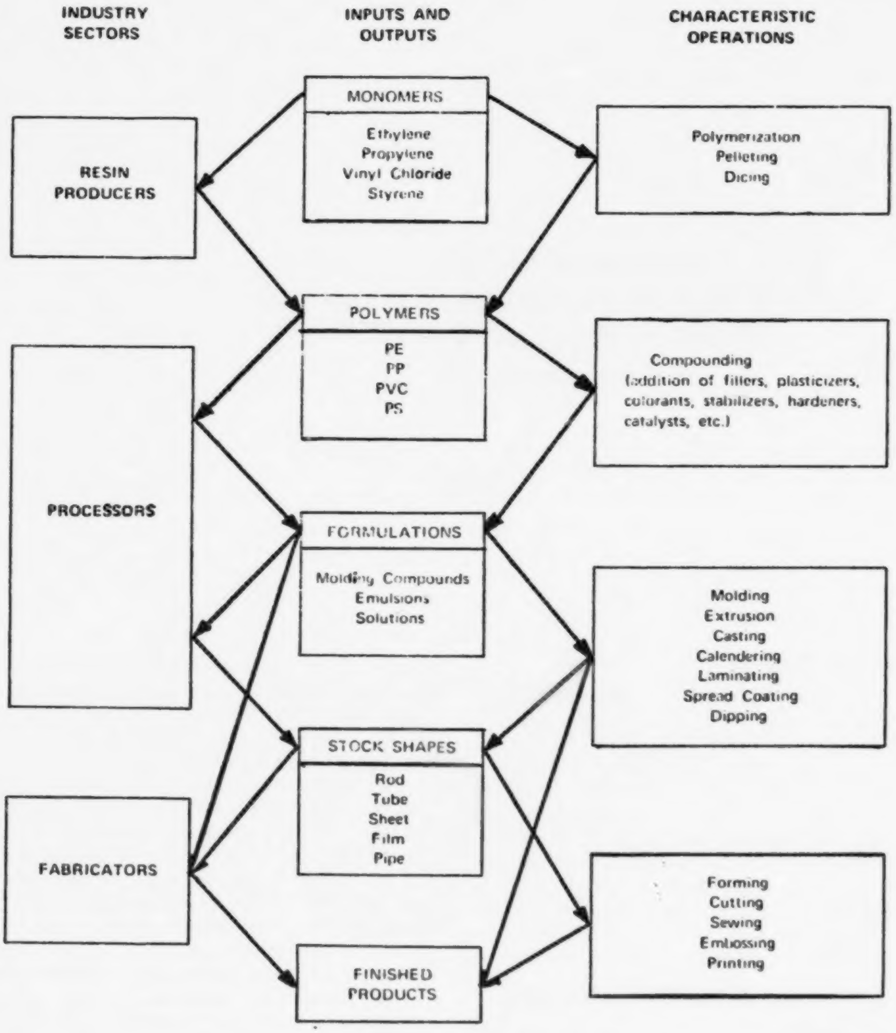
INDUSTRY SECTORS
INPUTS AND OUTPUTS
CHARACTERISTIC OPERATIONS
MONOMERS
Ethylene
Propylene
Vinyl Chloride
Styrene
RESIN PRODUCERS
Polymerization
Pelleting
Dicing
POLYMERS
PE
PP
PVC
PS
PROCESSORS
Compounding (addition of fillers, plasticizers, colorants, stabilizers, hardeners, catalysts, etc.)
FORMULATIONS
Molding Compounds
Emulsions
Solutions
Molding
Extrusion
Casting
Calendering
Laminating
Spread Coating
Dipping
STOCK SHAPES
Rod
Tube
Sheet
Film
Pipe
FABRICATORS
Forming
Cutting
Sewing
Embossing
Printing
FINISHED PRODUCTS

Figure 1: Structure of Plastics Industry

Industry Statistics

Thermoplastic resins have paced the growth of the plastics industry primarily because of demonstrated ease of fabrication, decreasing monomer prices, new technology, and economies of scale. Three types of thermoplastics have dominated this growth: polyolefins (PO), polyvinyl chloride (PVC), and polystyrene (PS). The present distribution of U.S. production capacity for large volume thermoplastics is shown in Table 1.

Industry statistics for polyolefins (SIC 28214) include both high- and low-density polyethylene (HDPE and LDPE, often lumped togehter as PE) and polypropylene (PP). Polyvinyl chloride, including copolymers containing over 50 percent PVC, accounts for over 80 percent of total vinyl resins (SIC 28212). Polystyrene, including the rubber-modified, high-impact copolymers, but not the more expensive styrene-acrylonitrile (SAN) or acrylonitrile-butadiene-styrene (ABS) resins, accounts for about two-thirds of total styrene resins (SIC 28213).

Production of all thermoplastic and thermosetting resins (SIC 28210) in the United States was 16 billion pounds in 1968, of which 12.3 billion pounds (over three-fourths of the total) represented thermoplastics. The aggregate growth rate of all thermoplastic resins is expected to level out at about 11 percent per year over the next decade, compared with an expected rate of about 5 percent per year for thermosets.

The top position in thermoplastics is unquestionably held by polyethylene resins, whose 1968 production volume of 4.5 billion pounds was nearly twice that of PVC, about two-and-a-half times that of straight and rubber-modified PS, and about five times that of PP.

Because each of the major thermoplastic resins has a unique spectrum of properties, each of them also has a similarly unique spectrum of markets (Table 2). Nearly half of all LDPE is used for film and sheet, whereas this use accounts for only a small part of the market for the other resins. HDPE is the dominant blow molding resin. Injection molding is the largest market for PS and PP; PP also finds a major market in fibers and filaments. The markets for PVC are more diverse than those for any other resin; in addition to its major uses in extrusions (particularly wire and cable), PVC dominates the phonograph record molding market and the calendared products market, and shares (with PS) the substantial markets in coatings and adhesives.

Industry Survey Procedure

Most of the required data on waste amounts and dispositions were previously unpublished and were available only through extensive personal contacts with appropriate industry sources.

The questionnaire for this study was submitted in three parts: Part I was directed to major polymer producers, Part II to plastics processors and fabricators, and Part III to manufacturers of waste disposal equipment. It solicited the following general types of information:

- the sources, amounts, and forms of polymer waste generated
- disposal methods in use, investigated, or planned
- satisfactory and unsatisfactory aspects of current disposal methods
- disposal equipment capabilities and costs.

In general, most industry contacts were very cooperative. However, several resin producers, each making more than one resin type, did choose to restrict their data responses to one

TABLE 1
Distribution of Production Capacity for Large Volume Thermoplastic Resins

Polymer			U.S. Producers	U.S. Plants	Estimated Capacity End of 1969 (billion lb./yr.)
PO	PE	LDPE	13	21	4.25
		HDPE	13	15	2.11
		PP	8	8	1.26
		PVC	23	35	3.72
		PS	15	30	2.54
					13.88

TABLE 2
1968 Markets for Large Volume Thermoplastics

Type of Use	Percent of Total Consumption of Each Resin				
	LDPE	HDPE	PP	PVC	PS
Molding	25	63	41	8	50
Extrusion	64	11	42	32	14
Calendering	—	—	—	28	—
Coating and Adhesives	—	—	—	16	—
Other Domestic Uses	9	17	7	11	20
Export	12	9	10	5	3
Total	100	100	100	100	100

type only, and this changed the originally planned balance of resin types covered in the survey. Of the seven reporting primary resin plants, four produce both high- and low-density polyethylene, two produce only high-density polyethylene, and one produces polyvinyl chloride. The reported data are thus highly weighted toward the polyethylene segment of the thermoplastic resin producers.

In the case of processors and fabricators, many companies volunteered to provide separate detailed responses for each of several plants or divisions. Tables 3 and 4 show the distribution of the 47 reporting plants accrding to principal operation, and according to principal application, respectively. Comparison of Tables 3 and 4 with the market data of Table 2 indicates that the survey of processors and fabricators represents a broad cross-section of the thermoplastics industry, for that part devoted to fibers and filaments, calendered products, and most coating applications.

TABLE 3
Distribution of Surveyed Processors and Fabricators by Principal Operation

Type of Operation	*Reporting Plants*
Compounding	2
Rotation Molding	2
Blow Molding	15
Injection Molding	4
Extrusion	16
Thermoforming	8
Total	47

TABLE 4
Distribution of Surveyed Processors

Type of Product	*Reporting Plants*
Molding Compounds	2
Film and Sheet	13
Foamed Articles	3
Flexible Packaging	5
Rigid Containers	17
Pipe, Conduit, Wire and Cable	3
Molded Toys, Housewares, etc.	4
Total	47

Data Reported by Resin and Plastics Industries

Based on the present survey, solid thermoplastic polymer wastes are estimated to be generated by the U.S. plastics industry at an average rate of 3.3 percent of resin production, equivalent to an estimated 1969 waste generation of 460 million pounds. One-third of the total waste is contributed by primary resin producers and two-thirds by plastics processors and fabricators.

Individual plants deviated considerably from the estimated average waste generation rates. Polyethylene resin producers reported that polymer wastes ranged from 0.5 to 4.0 percent of resin production and averaged 1.75 percent. Limited data obtained from producers of other resins suggest that they generate proportionately much less solid polymer waste, probably between 0.4 and 0.8 percent of resin production.

For plastics processors and fabricators, the amount of waste is not markedly correlated with the type of thermoplastic resin, but varies considerably as a function of the application (Table 5). Such critical applications as wire and cable insulation have an unreclaimable polymer reject rate generally exceeding 10 percent, whereas, at the other extreme, such noncritical items as molded toys, housewares, and decorative articles may have virtually zero nonreclaimable scrap.

Tables 6 and 7 show, respectively, the reported sources of polymer wastes and the reported distribution of physical forms of the waste before any change in form made specifically to facilitate disposal.

The companies surveyed had quite varied estimates of the prospects for change in the amounts of waste generated. A slight majority of each industry group forecast no significant change; however, the minority that did forecast change anticipated a reduction of from 20 to 50 percent of present waste amounts, primarily through improved salvage and reclaim

TABLE 5
Processing and Fabrication Waste as a Function of Product Type

Type of Product	*Reported Waste (Percent of Processed Polymer)*		
	Average	*Maximum*	*Minimum*
Molding Compounds	0.7	1.0	0.5
Film and Sheet	1.8	2.0	1.6
Flexible Packaging	1.4	3.0	0.5
Rigid Containers (incl. foam)	1.2	4.0	0.7
Wire and Cable	10.3	25.0	10.0
Pipe, Toys, Housewares, etc.	0.2	0.3	0.0

TABLE 6
Reported Sources of Polymer Wastes

Source	*Average Percent from Each Source* *Primary Resin Producers*	 *Processors and Fabricators*
Off-Grade Product	26	65
Emergency Dumps of Reactor	8	—
Normal Spillage, Contaminated	22	19
Cleanout and Maintenance	16	16
Removal from Effluent Gas or Liquid	20	—
Other (low melting wax, etc.)	8	—
	100	100

TABLE 7
Reported Physical Forms of Polymer Wastes

Waste Form	*Average Percent of Each Form* *Primary Resin Producers*	 *Processors and Fabricators*
Pellets	18	14
Chopped or Shredded	0	3
Dust or Powder	23	3
Random Large (100 lb.)	10	28
Random Small (100 lb.)	14	17
Other	35	35
	100	100

TABLE 8
Reported Present Polymer Disposal Practices

Type of Disposal	*Number of Reporting Plants* *Primary Resin Producers*	 *Processors and Fabricators*
Open Dumping	4	4
Sanitary Landfill*	2	32
Incineration	1	0
Unknown	—	11
	7	47

*Reported by plants to be "sanitary."

techniques rather than through process changes leading to lower initial waste generation. All industry sources agreed that fluctuations in the price of plastic scrap could have a major effect in drawing the line between scrap and waste.

Polymer waste disposal practices presently employed by the plastics industry were reportedly limited to open dumping, sanitary landfill, and incineration (Table 8). Resin producers (representing relatively concentrated sources of polymer wastes, reportedly ranging from 0.85 to 22.5 tons per day per plant) typically handled their own waste disposal on company land. By contrast, plastics processors and fabricators (representing a much larger number of individual plants, with correspondingly less waste per plant) typically depended on public agencies or private contractors for their waste disposal.

Based on the disposal cost data reported in this study, estimates are that the U.S. plastics industry spent about $5.6 million in 1969 to dispose of its 460 million pounds of solid polymer waste, for an average unit disposal cost of about $24.30 per ton. (This includes the highly labor-intensive costs of initial waste collection and hauling, as well as direct disposal operating costs and equipment amortization.) Resin producers as a group reported an aggregate average unit disposal cost of $26.00 per ton, whereas the corresponding figure for processors and fabricators was $23.50 per ton. However, individual plants reported unit disposal costs deviating widely from the above averages. This presumably reflects wide variations in cost accounting practices. The available data do not permit a reliable breakdown of costs by disposal technique; the computed mean cost predominately represents the use of sanitary landfill.

Evaluation of Alternative Disposal Methods

For most parts of the United States, sanitary landfill will remain the most economical and practical of the "acceptable" disposal methods for solid polymer wastes, at least for the next 10 years. As available landfill sites become more distant from waste sources, the economic advantage will shift to incineration, even though simultaneously the pressures of stricter air pollution regulations will force the use of modern, well-supervised, highly automated incineration equipment provided with efficient effluent gas cleaning accessories. Looking still further into the future, the optimum long-term solution to the disposal of industry's solid polymer waste will probably be through efficient, economical, centralized disposal facilities, each capable of processing all types of waste from many plants in a given area. Only in such large centralized plants is it likely to be economical to combine waste disposal with recovery of the fuel value of the waste through steam or power generation.

Solid Waste Management in the Industrial Chemical Industry*

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and
J. KIRBY HOLCOMBE
The Travelers Research Corporation

The Travelers Research Corporation

The Travelers Research Corporation is conducting a study on solid waste management in the industrial chemical industry. This industry is the largest component of the chemical industry and manufactures virtually countless products by means of tremendous numbers of processes.

Data on solid waste management practices are being obtained through plant interviews and mail questionnaires. A total of 24 in-depth plant interviews will be conducted, and the questionnaires will be sent to over 2,100 plants.

At the present time, the study is partially completed. The questionnaire has been approved by the Bureau of the Budget, and it was recently mailed. This questionnaire was developed and refined through five initial plant visits. The visits also served to acquaint us with the variety of solid waste produced and with some of the waste management practices used by the industry.

Our study team is presently beginning to conduct 19 additional plant interviews at representative plants. Questionnaire returns and plant interviews should be complete by June, 1970, at which time the data obtained can be compiled and analyzed, and a final report on the industry prepared.

Included in the industrial chemical industry are those chemicals under Standard Industrial Classification (S.I.C.) #281. This category is further divided into establishments primarily engaged in the following:

S.I.C. #2812: the manufacture of alkalies and chlorine;

S.I.C. #2813: the manufacture of industrial gases, including acetylene, carbon dioxide, hydrogen, nitrogen, etc.;

S.I.C. #2815: the manufacture of cyclic intermediates, dyes, organic pigments, and cyclic crudes; this includes cakes and toners, coal tars, derivatives of benzene, toluene, and other cyclic chemical products and products of medium and heavy oil, such as creosote oil, napthalene, and anthracene;

S.I.C. #2816: the manufacture of inorganic pigments, including iron colors, lead pigments, titanium pigments, and zinc oxide pigments;

S.I.C. #2818: the manufacture of organic chemicals not included in the previous categories; this includes a wide variety of chemicals, solvents, polyhydric alcohols, synthetic perfume and flavoring materials, rubber processing chemicals, plasticizers, and synthetic tanning agents;

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*This work is being performed for the U.S. Department of Health, Education and Welfare, Public Health Service, Bureau of Solid Waste Management, under Contract No. CPE-69-5.

S.I.C. #2819: the manufacture of inorganic chemicals not included in the previous categories, such as inorganic salts of sodium, potassium, aluminum, calcium, etc.; inorganic compounds such as alums and ammonia compounds; rare earth metal salts; and elemental bromine, fluorine, and alkali metals.

Not included in S.I.C. #281, and therefore excluded from this study, are the mining, milling or other preparation of natural potassium, sodium or boron compounds, plastic materials, synthetic rubber, essential oils, wood distillation products, rayon and other synthetic fibers, paints, and petroleum refinery products.

Figure 1 illustrates how solid waste generation might occur and how these materials might be generally classified in a typical chemical plant. Within a hypothetical plant, with supplies and raw materials entering through a shipping and receiving department and various solid waste leaving the plant at numerous points (numbers 1 to 13), there are five principal sources generating solid waste:

1. Sanitary and cafeteria facilities: waste paper, garbage, etc.;
2. Shipping and receiving: paper sacks, cardboard and metal drums, cans, bottles, and other materials used as shipping containers for plant materials and products;
3. Other sources of rubbish: plant production areas, construction or demolition areas, offices, etc.;
4. Basic production process: filter cakes, sludges, still bottom sediments from such equipment as scrubbing towers, solids retained by air pollution control equipment, etc.;
5. Product assembly and finishing: waste trimmings, off-products, etc.

Waste from the first three sources can be classed as nonprocess waste and the latter two as process waste. The nonprocess waste is similar to municipal waste and is most often handled as such. The nature of process waste, however, is related to the wide variety of manufactured chemicals. It can be a function of many factors, including the processes used, size of operation, capacity for by-product reprocessing and utilization, and the source of raw materials.

It is apparent that this study encompasses a staggering number of chemical products. To inventory the production process of each chemical from the standpoint of the solid waste generated, including chemical composition of the wastes, would require time and effort well beyond the scope of this project. Solid waste categories had to be defined to reduce these chemical wastes to manageable proportions.

Some chemical plants produce hundreds of chemical products by as many different processes. Products, as well as their associated wastes, had to be grouped into major categories. Typical process waste categories used for this study are filter residues, sludges, tars, flyash, and off-quality products.

For example, in the alkali and chlorine industry (S.I.C. #2812), the production of sodium carbonate or soda ash by the Solvay process produces a waste sludge. The sludge stems largely from the impurities in the limestone and consists of unreacted limestone, sand, and calcium sulfate. Substantial quantities of these wastes are slurried and pumped to large lagoons or waste beds. The material is compact and solid and has been built over in many instances. In other cases, completed waste beds may be covered with topsoil and seeded. The production of chlorine by electrolytic means is also a major process in the SIC #2812 group, but produces no major waste material.

The only product within the industrial gas industry (SIC #2813) found to produce a substantial solid waste during production is acetylene. In the carbide process, hydrated lime is produced. This material may be used in agricultural applications, but it is more valuable as a neutralizing agent for acid wastes. When acetylene is produced from natural gas, soot is a by-product, and in the process that uses paraffin hydrocarbon pyrolysis, tar is produced.

In SIC group #2815, the production of intermediate coal tar products and crudes produce filter cake wastes and still bottoms. These wastes result when volatile organics are distilled off as valuable products. The residues are frequently disposed of by incineration.

Most of the inorganic pigments are derived almost directly from ores. The solid waste resulting from this type of production consists of inert matter removed by filtration or sedimentation from the raw materials used in their manufacture. Some nonpigment solids are disposed of as landfill along with the pigment dust collected from cyclone separators or scrubbers.

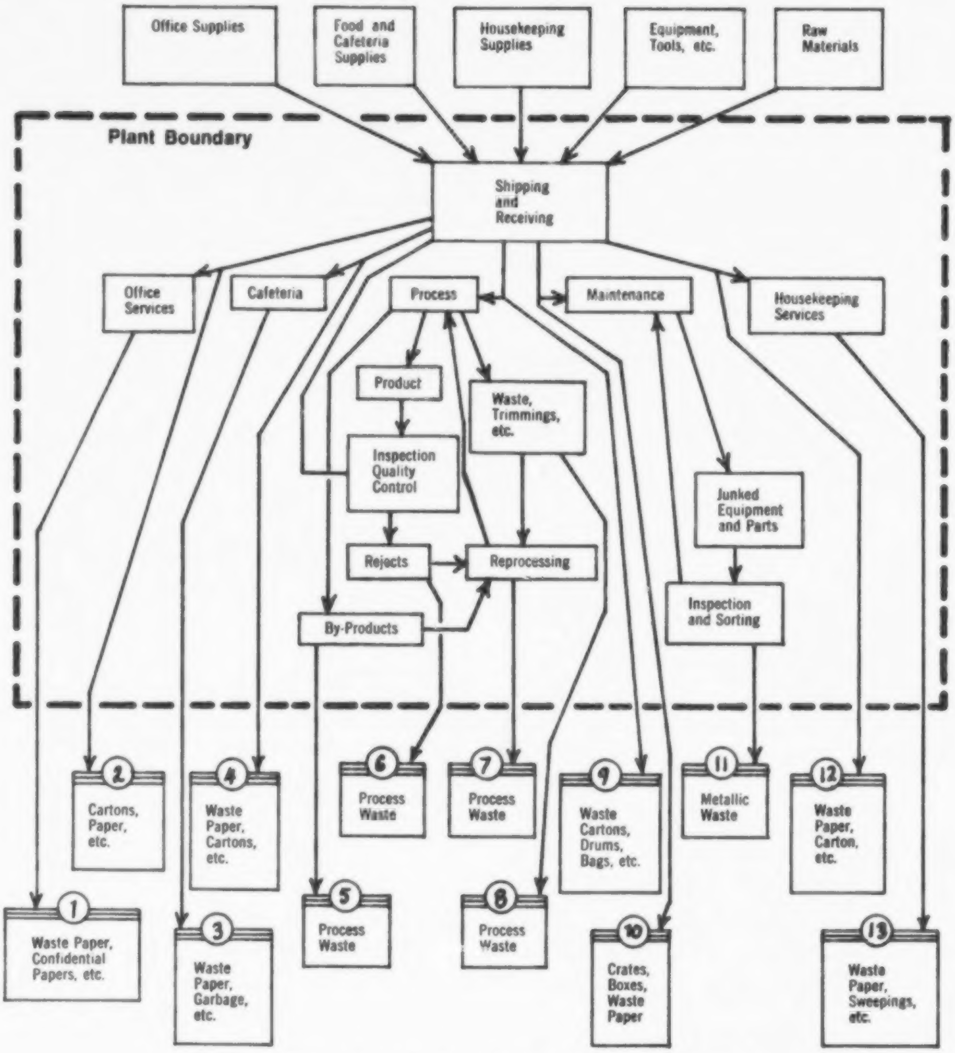
Office Supplies
Food and Cafeteria Supplies
Housekeeping Supplies
Equipment, Tools, etc.
Raw Materials
Plant Boundary
Shipping and Receiving
Office Services
Cafeteria
Process
Maintenance
Housekeeping Services
Product
Waste, Trimmings, etc.
Inspection Quality Control
Rejects
Reprocessing
By-Products
Junked Equipment and Parts
Inspection and Sorting
2 Cartons, Paper, etc.
4 Waste Paper, Cartons, etc.
6 Process Waste
7 Process Waste
9 Waste Cartons, Drums, Bags, etc.
11 Metallic Waste
12 Waste Paper, Carton, etc.
1 Waste Paper, Confidential Papers, etc.
3 Waste Paper, Garbage, etc.
5 Process Waste
8 Process Waste
10 Crates, Boxes, Waste Paper
13 Waste Paper, Sweepings, etc.

Figure 1: Solid Waste Generation from a Hypthetical Industrial Chemical Plant

Both the sulfuric and chloride processes used to produce titanium dioxide pigments (which have substantially replaced lead-base pigments in recent years) result in solid waste that require special disposal means. The wastes produced are ferrous sulfate or copperas, titanium dioxide or wash waters, and a mud containing mainly unreacted ore.

Although the crystalline ferrous sulfate is a solid, it is water soluble and cannot be disposed on land without causing serious ground and water pollution problems. Although some of this material is salable, much of the material is dumped at sea, along with the waste mud. The titanium dioxide in wash waters is sometimes lagooned and the sediment periodically removed and landfilled.

Under the categories of organic and inorganic chemicals not elsewhere classified (S.I.C. #2818 and 2819), a broad range of chemicals and processes produce solid waste. Inorganic chemical production probably produces the greatest quantities of solid waste. For instance, when large quantities of gypsum are produced, ores digested with sulfuric acid produce such inorganic acids as phosphoric and hydrofluoric. The waste gypsum is usually stored on land or buried.

One problem with respect to surveying chemical solid waste is in defining what constitutes a solid or a liquid waste. For example, tars produced from the manufacture of dye, rubber chemicals, pigments, and intermediates are actually heavy liquids but are not miscible with water. They can be stored in dumpster-type boxes and disposed of by impoundment on land or by incineration. For the purposes of this study, since they potentially can cause "land pollution," they have been treated as a solid waste. Another case of controversy concerns suspended solids that are lagooned. In these cases, the solids settle out and are periodically removed. Initially, the waste is liquid and is handled as such, but eventually a solid is produced that must be dealt with. Dissolved material that eventually crystallizes presents a similar problem. Another case of this type involves material generated by the process as a solid but dissolved for final disposal as a liquid waste.

In addition to this solid/liquid waste controversy, there is the similar quandary of whether a waste is really a usable by-product. In many instances, economic conditions determine the percentage of waste material that may be sold as a by-product, and these conditions fluctuate. Many wastes are stored in the hope that a market will develop and, thus, convert the waste to a by-product. In other instances, such as with off-product waste, it may be stored until time is available or demand for the material is up; this would justify its upgrading to an acceptable and salable product.

In some cases, small companies buy a waste material from an industrial plant and convert it to a salable product, where the industry producing the waste may not own the equipment to effect the conversion or overhead may be too high to make this profitable. In some cases, the industry may buy back this processed waste. The reprocessing companies provide a valuable service to the industry in many cases, but the nature of their work tends to make them marginal. If they are forced out of business when economic conditions change, the industry is then faced with disposal of its waste material.

We hope that through the analysis of the data obtained in this study we can clarify and resolve some of the liquid/solid and by-product/waste uncertainties.

A major step to control the quantity of solid waste produced by chemical manufacture can start with the basic process operations. Industrial representatives concerned with pollution control believed that more attention to waste minimization on the part of people charged with chemical process design and production is a logical path to smaller waste loads. A fuller realization on the part of these individuals of the environmental and in-plant problems and costs created by process wastes is needed. For most chemical processes, the total quantity of waste material emitted to air, water, and land is not well-known. The efficiency of a process is determined from the standpoint of the production of the desired chemical. Waste production should be considered an important component of the production efficiency determination. If this were the case, increased concern over the quantity and type of wastes produced would result.

This is particularly critical in view of the trend in chemical production toward more complex processes producing chemicals that are highly reactive and difficult to handle. The waste from these processes will produce complex disposal problems.

In this connection, it is most imperative that the designer of a process for a new chemical material also specify the manner in which the waste chemicals produced are to be disposed. In many cases, only these individuals are familiar enough with the chemical materials involved to detail adequate procedures.

The brief description we have presented of the solid waste aspects of the industrial chemical industry will be considerably expanded with the completion of the overall survey. This survey will present in part a general description of the chemical industry, including a compilation of the total numbers of products produced. Past, present, and future development and production patterns are being investigated. Basic production processes for the major industrial chemicals will be summarized. Much of this information will be developed on a national and regional basis from available literature and sources such as the Department of Commerce and the U.S. Tariff Commission.

By means of the mail questionnaires and plant interviews, detailed information on the character and quantity of solid waste and the problems of handling and disposal will be compiled. An attempt will be made to correlate the quantity of waste generated with parameters associated with plant or process characteristics. Future trends in solid waste management and the effect of chemical industry waste on surrounding communities are also being investigated.

The industrial questionnaire has been mailed to over 2,100 plants. This represents essentially every industrial chemical plant producing chemicals in commercial quantities. A limited number of copies of our questionnaire is available for those who might wish to review them.

Within the questionnaire, nonprocess wastes are categorized as combustible, noncombustible, and salvageable metal. For each category, quantities and sources are requested along with information on storage, disposal, cost of disposal, and physical and chemical characteristics. The plant is also asked to identify the operating parameter that most directly influences waste generation and to provide an approximate 5-year projection as to waste quantities, disposal practices, and costs.

Additional interview visits will be made to 19 representative chemical plants. The selection of plants was based on three factors: plant location, plant size, and area of major activity on the basis of four-digit S.I.C. classification.

To make the geographic selection tractable, a regional approach, employing the Bureau of the Census regions, was used. Plant size was based on total employment, since other factors such as production or capacity would be very difficult to obtain on a plant-by-plant basis.

To limit the selection to those regions most active in industrial chemical manufacture, each region was evaluated by assigning point values to several of the pertinent statistics presented in the 1963 census of manufacturers. The three regions with the greatest activity were Middle Atlantic (New York, New Jersey, and Pennsylvania), West South Central (Arkansas, Louisiana, Oklahoma, Texas), and East North Central (Ohio, Indiana, Illinois, Michigan, and Wisconsin).

Plant size was based on employment classifications of "large" (1,000 or more employees), "medium" (500 to 1,000), and "small" (under 500). For equitable distribution, it was assumed that nine visits would be made in the West South Central Region and 15 in the Middle Atlantic and East North Central. A random procedure was used to obtain the category combinations to be used in the selection of plants for visitation.

The plant visits provide the necessary contact with people directly involved in chemical production and waste management. This contact provides a control over the data obtained by questionnaire and assists in its interpretation and analysis. The insights of these people into present and future solid waste practices are essential to a description of the industry.

Although the study, as discussed in this interim report, is only partially complete, it is expected that the results should provide the Bureau of Solid Waste Management and industry with an overall view of chemical industry solid waste practices. This information will be useful in formulating future solid waste management plans and in revealing those areas where disposal problems exist and where further research is necessary.

Solid Waste Industrial Profiles Petroleum Refining

W. L. LEWIS
Humble Oil
and Refining Company

The petroleum industry has recognized for many years its responsibility to supply part of the energy needs of this nation and, at the same time, be a good industrial citizen and neighbor. This responsibility includes environmental cleanliness. Nuisance-free disposal of solid waste certainly falls within the scope of this responsibility.

In order to put the magnitude of petroleum refining solid waste disposal into proper perspective with the national situation, I have developed a few numbers from published data and made some estimates. Most published reports indicate that, on the average, each person in this country throws away around 5 to 6 pounds of solid waste each day. Petroleum refining operations generate about 90 pounds per day of solid waste per employee. This does indicate that our quantity problem is about 20 times greater than the average city. However, the problem of collection and transportation to a disposal site is usually much less than that of a city.

The physical composition and disposal of wastes from petroleum operations is not much different from municipal refuse. The detailed physical compositions were taken from a comprehensive study made in a large Gulf Coast refinery. At present, the most popular methods of disposal are by sanitary landfill and incineration.

The first part of the study was the determination of quantities and characterizations of the solid waste produced, both on a routine recurring and non-recurring basis. Other parts covered screening of methods and cost comparisons. Before developing any plans for adequate disposal, one must of necessity answer the question: "How much of what?" It was surprising to find how difficult this information is to accumulate. Knowledge of various facets of collection and disposal was scattered among many employees and not in the custody of one group.

The scope of this first effort was as follows:

(1) Quantities of solid and semi-solid waste were determined, including wastes from office buildings, lunchrooms, laboratories, machine shops, process units, and tanks.

(2) Certain sludges and other combustibles were analyzed for such characteristics as oil content, bottom sediment and water (BS&W), ash content and density. Heats of combustion were determined for certain wastes and estimated for others. Toxic and noxious materials were identified for special handling.

(3) The wastes handling system and need for segregating wastes were defined.

Approximately two man-years of effort were required and over 200 separate solid and semi-solid wastes were considered. In order to characterize the waste generated, it was decided to establish five general types of waste. A breakdown of the types selected follows:

A. Oily (oil content 5 percent to 95 percent)
B. Oil Coated (oil content below 5 percent)
C. Oil Free, combustible
D. Oil Free, non-combustible
E. Other (garbage, toxic, etc.)

The existing waste collecting system inside the refinery was defined and maps were prepared of waste collecting routes and in-plant disposal areas. It was determined that the total cost of the existing method of collection and disposal of

Type	Tons/Year
A. Oily Wastes (oil content 5% to 95%)	11,000
B. Oil-Coated Solids (oil content below 5%)	7,000
C. Oil Free, Combustible	11,000
D. Oil Free, Non-Combustible	15,000
E. Other (garbage - trash - toxic)	2,000
Total	46,000

Figure 1

Type	Quantity M Lbs/D	Density Lbs/CF	Moisture M Lbs/D Avg.	Moisture M Lbs/D Max.
Tank Bottoms	52.0	70	44.2	91.8
Wax-Asphalt	0.4	65	-	-
Trash-Garbage	50.0	25	13.8	16.5
Filter Solids	13.2	52	3.4	11.4
Scrap Plastic	1.6	50	0.1	0.1
Separator Sludge	140.0	75	119.0	119.0
Total	257.2		180.5	238.8

Figure 2

solid waste amounted to $9-$10/ton. Of course, this cost does not represent the latest techniques for nuisance-free disposal of all the wastes. That was the main objective of the study - to improve waste disposal practices.

Criteria for the selection of the disposal method were considered for each general type waste. Obviously, inert solids, such as certain spent catalysts or residue from incineration, would be disposed of by landfill. On the other hand, some combustible semi-solids have a tendency to coldflow and because of lower density rise to the surface in patches when buried. Therefore, it was assumed that both some landfill and some incineration may be required.

In any event, it is necessary to determine the maximum oil content of solids which can be handled economically by landfill or surface plowing. Viscosity and gravity of the oil are important considerations. For example, a high asphalt content would probably be satisfactory for landfill, while a waste containing the same amount of heating oil may be more difficult to handle. However, the maximum oil content that can be satis-

	Volatile Matter M Lbs/D		Fixed Carbon M Lbs/D		Total Combustible M Lbs/D		Ash M Lbs/D		Lower Heating Value Btu/Lb	
Type	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
Tank Bottoms	3.4	7.1	0.5	1.0	3.9	8.1	3.9	8.1	18.0	18.0
Wax-Asphalt	0.3	0.6	0.1	0.2	0.4	0.8	-	-	18.0	19.0
Trash-Garbage	24.4	29.2	10.4	12.5	34.8	41.7	1.5	1.7	5.0	6.0
Filter Solids	2.7	9.0	1.8	6.0	4.5	15.0	5.3	17.6	15.0	15.0
Scrap Plastic	0.1	0.1	1.4	1.7	1.5	1.8	0.1	0.1	17.0	17.0
Separator Sludge	3.1	3.1	1.0	1.0	4.1	4.1	17.9	17.9	18.0	18.0
Total	34.0	49.1	15.2	22.4	49.3	71.5	28.7	45.4		

Figure 3

Element	% of Total Solid Waste Production	Tons/Year
Landfill for Inert Solids	69	31,800
Oil Treatment for Semi-Solids and Sludges	20	9,200
Special Treatment	4	1,800
Incineration	7	3,200
Total	100	46,000

Figure 4

factorily handled by landfill will vary at different locations because of differences in the soil and in rainfall and other geographic conditions.

While the detailed tabulation of data obtained during the study represented the best analysis obtainable for the previous three years (1966-1968), all summaries developed included an estimate of future operations. This is a most difficult task because of the ever changing nature of refining process operations. This causes the solid waste quantities and qualities to also be ever changing.

Figure 1 shows a summary of the five general types of waste selected at the beginning of the study. For design purposes, more detailed data were developed to determine the best disposal method. In order to present this with figures, I have separated the data into two parts. Figure 2 shows type, quantity, density, and moisture. Figure 3 shows type, volatile matter, fixed carbon, total combustible, ash, and lower heating value.

The basis for design of future facilities was extracted from the detail characterization study. Based on the total quantity of waste produced, four elements of disposal were developed. An estimate of the percentage by each element is shown in Figure 4.

As part of the comprehensive study discussed earlier, several investment and operating cost comparisons were made. The following general conclusions were developed based on these comparisons:

- Landfill is less costly for inert wastes.
- Incineration for oily solids is about the same cost and less troublesome compared to landfill.
- Unit costs are lower for disposal in facilities of larger capacity.

Chemistry of Pyrolysis of Organic Solid Wastes

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The science or art of pyrolysis in the area of chemical analysis has been available to the research chemist primarily since the advent of gas-liquid chromatography. Previous to the availability of research grade gas chromatographs, it was difficult to use pyrolysis for study of complex molecules and/or mixtures of materials. Consequently, only in the last ten years has pyrolysis assumed a role in chemical analysis.

Let us define pyrolysis as the "chemical change brought about by the action of heat." It can also be thought of as destructive distillation in the absence of oxygen or other oxidants. Frequently, in laboratory-scale pyrolysis, a carrier gas such as hydrogen or helium is utilized. Hydrogen, of course, could easily enter into reaction with organic molecules in the hydrogenation of unsaturated compounds. Pyrolysis generally does not employ a catalyst, although in some chemical processes catalysts are used.

Pyrolysis as a commercial process has been in use for many years in the production of methanol, acetic acid, and turpentine from wood plus recovery of the residual charcoal. In only limited instances has the process been applied to organic solid waste. The promise of pyrolysis, despite the economics, is the production of simple organic molecules from material normally buried or incinerated. These simple organic molecules will serve as the building blocks for the synthesis of polymers and other petrochemical products.

One of the difficulties in pyrolysis, both on a laboratory or pilot scale, is the variation of effluent products. This, of course, is due to a change in operating conditions, such as temperature, rate of temperature increase, gas flow, feed materials, and other parameters. It has been shown that these factors can considerably alter the nature of the effluent.

Solid waste denotes a wide range of organic molecules, and to comment or speculate on all possibilities would be exceedingly difficult. We will confine our remarks to polymeric materials, to simple molecules, and, after a brief introduction to general refuse, to specific groups of compounds.

Kaiser and Friedman[1] studied pyrolysis of various refuse such as could be expected in municipal waste disposal. The organic material studied was mostly cellulose, but there were fats, proteins, hydrocarbons, and other polymeric materials present. The refuse was shredded and heated slowly to 1500°F, and the following products were observed:

Gases:	CO_2	20.3 - 43.1 Volume percent
	CO	15.7 - 45.1
	O_2	0.0 - 2.0
	H_2	2.8 - 22.2
	CH_4 & $C_n H_m$	16.9 - 28.2
	N_2	2.0 - 11.7

Liquids: Water, methyl alcohol, allyl alcohol, methyl acetone, ketones, methyl acetate, oils, and residual tars.

The variability in ratios of both gaseous and liquid products depends on the nature of the original organic compounds. Oxygenated molecules present in the waste will produce higher percentages of CO, CO_2, and O_2, while proteins, polyurethane, and other nitrogenated compounds will produce nitrogen gas. Higher ratios of polymeric hydrocarbons should produce more methane, ethane, and other paraffins. The liquids varied in constituency and consisted of some 80 compounds. The char was a significant proportion of the residual and consisted of carbonaceous material fused with metal, glass, and other inerts.

A significant phenomenon, and one noticed by everyone performing pyrolysis research, is that the reaction temperature and the rate at which this temperature is achieved greatly influence the distribution of products produced from a similar feed source. This, of course, can be explained chemically because reaction rates are temperature dependent and the activation energies required to initiate chemical reactions are widely distributed. Hence, a rapid increase to a given temperature (several seconds or less) would initiate a different set of reactions than a slow ascendancy to the same temperature.

D. A. Hoffman[2] performed essentially the same pyrolysis experiments on municipal refuse at the Utilities Department, San Diego, California. The same groups of products were reported: water, gases, liquids, and char. The gases were the same except for the addition of an unidentifiable constituent. A minimum of twenty-three liquid compounds were observed with nine being identified: methanol, ethanol, isobutanol, 3° - pentanol, propanediol, 1° - hexanol, and acetic acid. Some of the missing ketones were not identified or reported.

Some research has been performed on cellulosic materials since they are so prominent in solid waste. Stern, *et al.*[3] reported that pyrolysis of carbohydrates such as cellulose produced large volumes of gases, particularly hydrogen, carbon monoxide, carbon dioxide, and methane with some tarry residue. They empirically represented the above reaction as shown in equation I.

$$(C_6H_{10}O)_x \xrightarrow{\Delta} iCO_2 + jCH_4 + kH_2O + lH_2 + \text{residue} \qquad \text{(I)}$$

The equation, of course, does not explain any reaction pathways which might be present. Lincoln[4] and Kilzer and Broido[5] noticed in the pyrolysis of alpha-cellulose that levoglucosan always seemed to be present. The latter group postulated the following pyrolytic decomposition pathway:

(1) Intermolecular reaction with loss of water.

(2) Formation of levoglucosan in a rearrangement.

(3) Rupture of bonds to form products.

Lincoln used four thermal sources to induce pyrolysis: resistance furnace, carbon arc (300°C), carbon arc (600°C), and xenon flashtube. Only the latter produced a large quantity of gases; the others produced considerable quantities of liquids, tar, and char. The xenon flashtube exposure time was 0.5 milliseconds with a peak irradiance energy of 3000 cal/cm^2/sec. The other energy sources have exposure times of seconds or hours with much lower irradiance energy. Evidently the chemical reactions to producing only gaseous products have very high energies of activation.

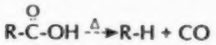
Farre-Rius and Guiochon[6] support the above data with some calculations based upon kinetic and thermodynamic considerations. Using polytetra - fluoroethylene, polystyrene, and polyethyleneglycol adipate, they were able to calculate the temperatures where flash pyrolysis was complete at two different heating rates. The actual pyrolytic decomposition is complete at a temperature below that of the equilibrium temperature of the pyrolytic device used (600°C - 800°C).

Heat Source	*Heat Rate (°C/sec)*	*Temperature of Polystyrene*	*Complete PTFE*	*Pyrolysis (°C) PEGA*
Pyrolysis Coils	300	407	533	564
Induction Heating	2×10^4	498	603	690

This data, plus any deviations from the assumptions of an extrapolatable rate constant and linear heating, would support the theory that pyrolysis is completed at temperatures less than the equilibrium temperature of the heat source. This means that the decomposition of materials by pyrolysis is controlled by the heating rate of the device and by heat transfer to the sample and not by the equilibrium temperature of the heating device. This could explain why it is very difficult to obtain reproducibility in pyrolysis between two different instruments.

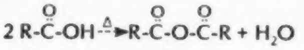
Some research has been performed on actual elucidation of pyrolytic decomposition reactions. A discussion of several of these characterizations will constitute the remainder of the paper.

The reduction of monobasic free fatty acids to their end products was studied by Hsu, *et al.*[7] and Bell and Reed.[8] The general decomposition reaction is shown in equation II.

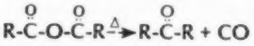


$$R\text{-}\overset{O}{C}\text{-}OH \xrightarrow{\Delta} R\text{-}H + CO \qquad (II)$$

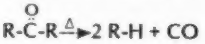
The proposed mechanism is shown in equations III, IV, and V.



$$2\,R\text{-}\overset{O}{C}\text{-}OH \xrightarrow{\Delta} R\text{-}\overset{O}{C}\text{-}O\text{-}\overset{O}{C}\text{-}R + H_2O \qquad (III)$$



$$R\text{-}\overset{O}{C}\text{-}O\text{-}\overset{O}{C}\text{-}R \xrightarrow{\Delta} R\text{-}\overset{O}{C}\text{-}R + CO \qquad (IV)$$



$$R\text{-}\overset{O}{C}\text{-}R \xrightarrow{\Delta} 2\,R\text{-}H + CO \qquad (V)$$

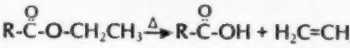
There is a lot of gas evolved in pyrolysis of fatty acids: hydrogen, carbon dioxide, and carbon monoxide. The carbon monoxide will evolve from the decomposition of intermediate ketones. Many chemists feel that there is a free-radical mechanism occuring in this decomposition which would account for the presence of paraffins with both higher and lower carbon number than the parent fatty acid and the large quantities of hydrogen and carbon monoxide evolved. This type of mechanism has also been suggested by Wolf and Walker[9] and others in their pyrolytic studies of hydrocarbon decomposition. They suggest that the primary molecule breaks into two free radicals and the free radicals extract a hydrogen molecule from another primary molecule forming a large free radical. Subsequent decomposition of this large free radical occurs in certain definite steps. The product distribution of the decomposition of the primary molecule can then be detected and, under the same conditions, reproduced. Equations VI-VIII suggest the reactions without regard for termination reactions.

$$RH \xrightarrow{\Delta} R'\cdot + R''\cdot \qquad (VI)$$

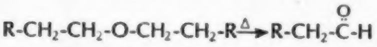
$$R'\cdot + RH \xrightarrow{\Delta} R'H + R\cdot \qquad (VII)$$

$$R\cdot \xrightarrow{\Delta} \text{Products} \qquad (VIII)$$

There have been other pyrolysis studies which elucidated some chemical kinetic information. King and Stanonis[10] used pyrolysis of substituted cellulose esters and ethers to demonstrate the following two decomposition reactions.



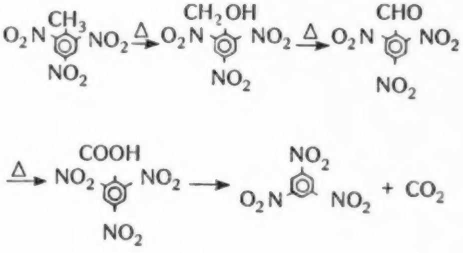
$$R\text{-}\overset{O}{C}\text{-}O\text{-}CH_2CH_3 \xrightarrow{\Delta} R\text{-}\overset{O}{C}\text{-}OH + H_2C{=}CH_2 \qquad (IX)$$



$$R\text{-}CH_2\text{-}CH_2\text{-}O\text{-}CH_2\text{-}CH_2\text{-}R \xrightarrow{\Delta} R\text{-}CH_2\text{-}\overset{O}{C}\text{-}H + R\text{-}CH_2\text{-}CH_3 \qquad (X)$$

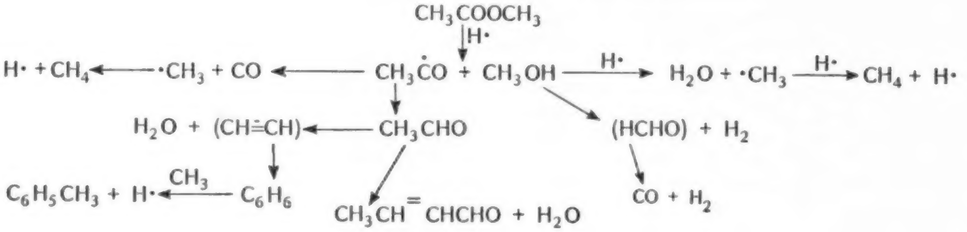
By analyzing the decomposition products by gas chromatography, they were able to demonstrate that the above two reactions are valid. Those compounds studied were cellulose 2-ethylhexanoate and 3,5,5-trimethylhexanoate; and benzyl, benzohydryl, and trityl ethers.

Rogers[11] studied the primary decomposition mechanism of 2,4,6-trinitrotoluene (TNT) using pyrolysis and thin-layer chromatography. At low temperature pyrolysis (300°C), the following reactions occur:



There are also some side reactions which follow more reductive pathways.

The final discussion of pyrolysis chemistry is a study made by Wolf and Rosie[12] on some twenty different molecules. In particular, a careful study of the decomposition products of methyl acetate revealed some features about the entire reaction system. The series of reactions given show pathways to pyrolysis products.



This study was quite significant in that free-radical mechanisms were used and old established chemical pathways were verified.

The research work cited here and other studies in chemical research of pyrolysis of polymers and smaller organic molecules reveals that free radical mechanisms are being postulated and that there are no unusual reactions occurring (or detected). Much more research is obviously needed in order to elucidate chemical reactions in complex mixtures such as solid waste.

REFERENCES

1. Kaiser, E. R. and S. B. Friedman. "The Pyrolysis of Refuse Components", 60th Annual Meeting AICHE, November, 1967.

2. Hoffman, D. A. "Burns Refuse Without a Flame", *The American City, Vol. 82*, No. 2, (Feb. 1967), pp. 102-104.

3. Stern, E. W., A. S. Logoidico, and H. Heinemann. "Approach to the Direct Gasification of Cellulosics", I & E.6. *Progress Design and Development, Vol. 4*, No. 2., (April, 1965), pp. 171-173.

4. Lincoln K. A. "Flash Pyrolysis of Solid Fuel Materials by Thermal Radiation", *Pyrodynamics, 2*, pp. 133-143.

5. Kilzer, F. J. and A. Broido. "Speculation on the Nature of Cellulose Pyrolysis", *Pyrodynamics, 2*, pp. 151-163.

6. Farre-Rius, F., and G. Guiochon. "On the Conditions of Flash Pyrolysis of Polymers as Used in Pyrolysis-Gas Chromatography", *Analytical Chemistry, Vol. 40*, No. 6, pp. 997-999.

7. Hsu, H., J. O. Osburn, and G. S. Grove, Jr. "Pyrolysis of the Calcium Salts of Fatty Acids", *Ind. Eng. Chem., Vol. 42*, (1950), pp. 2141-2144.

8. Bell, J., and R. I. Read. "Pyrolysis of Salts of Organic Acids", *Nature, Vol. 165*, No. 4193, pp. 402-403.

9. Wolf, C. J. and J. O. Walker. "New Chromatography Technique is Promising", *Oil and Gas Journal*, March 31, 1969, pp. 69-73.

10. King, W. D. and D. J. Stanonis. "Determination of the Substituent Content of Certain Cellulose Esters and Ethers by Pyrolysis and Gas Chromatography", *Tappi, Vol. 52*, No. 3, March, 1969.

11. Rogers, R. N. "Combined Pyrolysis and Thin Layer Chromatography", *Analytical Chemistry, Vol. 39*, No. 7, June, 1967.

12. Wolf, T. and D. M. Rosie, "The Pyrolysis-Gas Chromatography of Simple Organic Molecules", Analytical Chemistry, *Vol. 39*, No. 7, June, 1967.

Other References of Interest

13. Tsuge, S., T. Okunoto, and T. Takeuchi. "Study of Thermal Degradation of Fractionated Polystyrenes by Pyrolysis Gas Chromatography", *J. of Chromatographic Science, Vol. 7*, April, 1969, pp. 250-252.

14. Seymour, R. B. *Ind. Eng. Chem., Vol. 61*, No. 8 (1969)

15. Petru, K. *Plastecke Hmoty a Kavenk, Vol. 6*, No. 6, (1969)

16. Hagen, E. *Plaste u Kautschuk, Vol. 15*, No. 10, (1968)

17. LeMoan, G. *Ann. Pharm. Fr., Vol. 17*, No. 2, (1969)

18. Rasch, R. *Verpackungs-Rundshau, Vol. 19*, No. 10, (1968), Plastics Monthly 69-02, B36-90173.

Production of Organic Compounds by Partial Combustion and Pyrolysis of Solid Waste Materials

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The problem of disposing of the huge quantities of solid waste, which accumulate as a by-product of our modern society, is of growing importance to the nation. With the marked population increases which have occurred in the past few decades, people are now crowding in on one another to a degree where it becomes most difficult to hide our refuse. Besides an increase in the total quantity of waste produced as a result of population increase, the quantity of waste produced per capita has greatly increased because of changes in our standard of living. In addition to these changes in the quantity of solid waste produced, the chemical and physical composition of refuse has changed. These changes have, in general, complicated the problem of satisfactory disposal. The methods which have been used in the past are now being found to be far from satisfactory under even the best of conditions and are often found to be completely intolerable. Thus, the need for considering totally new approaches to the problem is apparent.

The approach that has been used in the present work has been to view domestic and industrial refuse, not so much as material to be disposed of, but rather as a potential resource. Such refuse usually contains a high proportion of organic matter made up of carbon, hydrogen, and oxygen for the most part, in about the proportions found in cellulose. The composition of a typical municipal refuse, as reported by Kaiser,[1] is shown in Table 1. It can be seen that the organic material represented by the analysis shown can serve as the basis for the creation of a host of new compounds through a reforming process similar to that used for reforming petroleum or natural gas.

Previous work involving partial combustion and pyrolysis of organic material includes the work of Dimitri, Jongedyk and Lewis,[2] who used destructive distillation in a fluidized bed for the breakdown of powdered hardwood. The objective of this work was to recover useful products. Re-

TABLE 1
Analysis of a Composite Municipal Refuse

	*Ultimate Analysis-%**	*Recalculated on Dry Basis-%*	*Percent of Organics*
Moisture	28.0	—	—
Carbon	25.0	34.7	50.0
Hydrogen	3.3	4.6	6.6
Oxygen	21.1	29.3	42.2
Nitrogen	0.5	0.7	1.0
Sulfur	0.1	0.1	0.2
Ash and Metal	22.0	30.6	—
	100.00	100.00	100.00

*Data of E. Kaiser
Proceedings of 1968 National Incinerator Conference

finements in this technique were provided by Morgan, Armstrong, and Lewis.[3] More recently Hoffman and Fitz have described work on the pyrolysis of solid municipal wastes.[4]

Approach

In the present work, studies have been made of the types of products which result from the reaction of selected organic materials, which are commonly discarded, with limited quantities of air in a fluidized bed. Such materials included paper, leaves, and "Orgro", a dried sewage treatment plant sludge.

Under conditions of complete combustion, it may be expected that organic materials will yield primarily such products as carbon dioxide, sulfur dioxide, oxides of nitrogen, and water vapor. However, if the reaction occurs in a deficiency of oxygen, the combustion is incomplete and a variety of products are formed.[5] Some typical combustion reactions under both total and partial combustion conditions are shown in Figure 1. It can be seen that even the simplest of hydrocarbons may yield a variety of products under conditions of partial combustion. As the complexity of the fuel increases, so also does the variety of possible products increase. In the case of a material such as paper, a major component of domestic refuse, the list of possible products is considerable.

TOTAL COMBUSTION

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

PARTIAL COMBUSTION

$$2CH_4 + O_2 \rightarrow 2CO + 4H_2$$

$$CO + H_2 \rightarrow HCHO$$

FORMALDEHYDE

$$CO + 2H_2 \rightarrow CH_3OH$$

METHANOL

Figure 1

Experimental

A diagrammatical sketch of the apparatus used in the work is shown in Figure 2. As can be seen, measured quantities of air and nitrogen were blended and fed to the bottom of an electrically heated reactor. The gas mixture supported the finely divided waste material in a fluidized state, providing the necessary oxygen and carrying off reaction products from the top of the reactor. In most runs, the sample charged to the reactor consisted of a 50-50 mixture of waste material plus sand or glass beads. The latter was added to improve fluidization characteristics and to serve as a heat sink. The solid waste material was prepared by pulverizing in a Waring blender or other suitable grinder. The unheated pilot column, shown in Figure 2, was used periodically to establish the total gas flow required to suitably fluidize a sample of a given size.

The products produced by the reaction passed through a series of traps held at progressively lower temperatures. The first trap consisted of a water cooled Leibig Condenser and flask, and was found to condense some water plus high-boiling organic materials. The second trap was cooled with ice water and in this trap the major portion of the water produced was collected. In addition, a small amount of organic material was collected. In the third trap, which was cooled by a dry ice-acetone mixture, the bulk of the organic material was found. In some runs, the gases from the third trap were adsorbed in a column filled with silica gel and cooled in a dry ice-acetone bath.

Runs were made using ratios of air to nitrogen which varied from zero to infinity. Temperatures which were studied ranged from about 500°F to as high as 1900°F.

Analytical

A number of analytical techniques were used to identify components in the product samples. Methods used included wet chemical analysis, gas chromatography, mass spectroscopy, and infrared spectroscopy.

The small amounts of liquid samples obtained made it difficult to apply wet chemical analysis except in a qualitative way. The colorimetric method of Feldstein[6] was useful in confirming the presence of appreciable quantities of formaldehyde and methanol in aqueous samples. Determination of pH was useful as an indication of the presence of acidic or basic components.

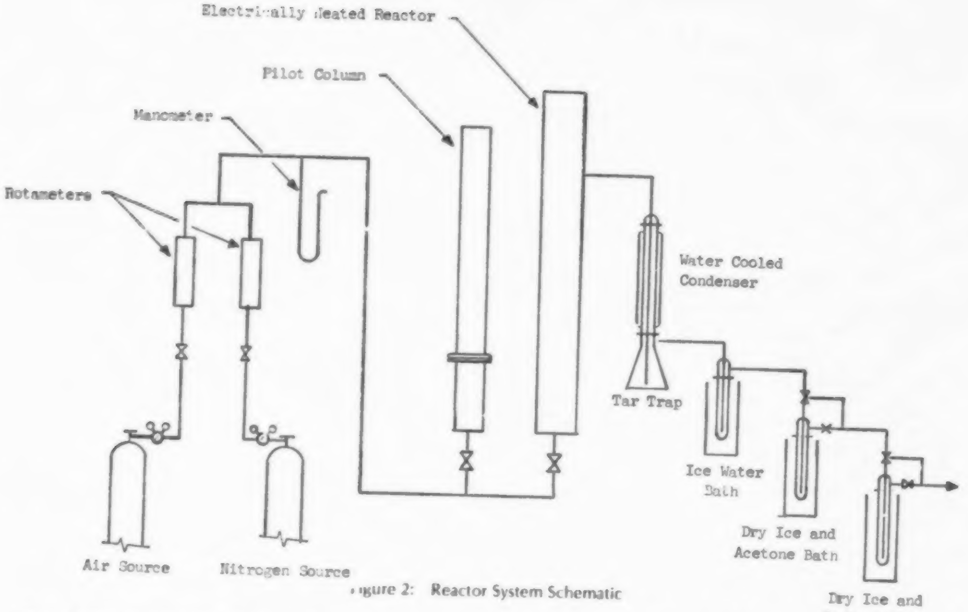


Figure 2: Reactor System Schematic

Gas chromatography was found to be particularly useful in these studies. Liquid samples were separated into major fractions with a Hewlett Packard, Model 775 Prepmaster Unit, and these fractions examined with either the analytical side of this unit, or a Hewlett Packard, Model 5754A research gas chromatograph. Both units were equipped with flame ionization and thermal conductivity detectors. Column packings used included Polypack-1, Porapak Q, and Porapak N. Chromatograms of pure materials suspected to be products were run to obtain retention times, which served as a guide to identifying major peaks obtained with product samples. A peak attenuation method was also used, whereby a pure material suspected to be present was added to a sample and its effect upon the resulting chromatogram observed. A syringe reaction technique, described by Hoff and Feit,[7] was used extensively with samples obtained from studies with leaves. In this method, selected active reagents are introduced into the syringe used to inject samples into the chromatograph. Such a reagent will react with specific materials or classes of materials suspected to be present. As a result, the peaks corresponding to these materials will decrease, and the peaks corresponding to resulting products will increase in the resulting chromatogram. This provides confirmatory evidence of the presence of these materials.

Infrared spectroscopy was found to be useful in identifying certain product components. This method was used extensively in the work on "Orgro". Mass spectroscopy was attempted but resulted in spectrums of extreme complexity. This method was not particularly useful. Details of the techniques used, together with the specific operational data, are furnished and described elsewhere.[8,9,10]

Results

The composition of paper and leaves as used as feed materials to the reactor in these studies is shown in Table 2. No analyses for the dried sewage sludge have been given because of extreme variability of samples. Material balances on the system invariably gave low product yields because of the small size of the initial charge and leaks which were inevitable to reactor operation.

Reaction Runs Using Paper

A summary of the operating conditions investigated for various runs, together with the sample size and amount of residue obtained, is given in Table 3.

The small amount of high boilers which were obtained in most runs, and the high viscosity of

TABLE 2
Feed Materials Composition

	Perentages Paper	Leaves
Moisture (as received)	4.07	1.04
Ultimate Analysis (dry)		
C	51.21	55.72
H_2	5.85	5.37
O_2	41.14	28.72
N_2	0.04	4.20
S	0.12	0.11
Ash	1.57	5.88

TABLE 3
Summary of Paper Reaction Runs

Sample No.	*Sample Size Grams*	*Air:N_2 Ratio*	*Residue Grams*	*Temp. °C*	*Liquid PH*
1	15	2:1	3.5	458	2.5
2	15	2:1	0.7	480	2.5
3	15	1:1	1.4	532	3.5
4	20		0.1	534	3.5
5	20	0	6.7	534	3.0
6	20	2:1	6.0	523	2.5
7	25	0	7.3	546	3.0
8	30	3:1	6.2	529	2.5
9	35		7.0	580	3.0
10	40		10.0	532	3.0
11	40	2:1	10.4	558	3.0
12	40	3:1	10.0	548	3.0

this fraction, made analysis most difficult. Attempts to determine the components in this group were made but no definitive results were obtained.

Principal efforts were directed towards identifying products present in the liquid fraction. Gas chromatography proved to be the most effective method available. As an aid in identifying the product materials, the retention times for a number of pure materials, thought possibly to be present, were determined. These results have been reported elsewhere.[10] By matching retention times of components with those of known samples, a number of products have been identified with a reasonable degree of certainty. These products included water, formaldehyde, acetic acid, and formic acid. These tentative identifications were substantiated by adding small amounts of suspected pure components to the original samples and observing the changes produced in their chromatograms. Typical results are shown graphically in Figures 3 and 4. The presence of acidic compounds was verified by the low pH of these liquid samples which ranged from 2.5 to 3.5. Specific values are given in Table 3. The presence of the above products was tentatively confirmed in several samples by wet chemical methods.

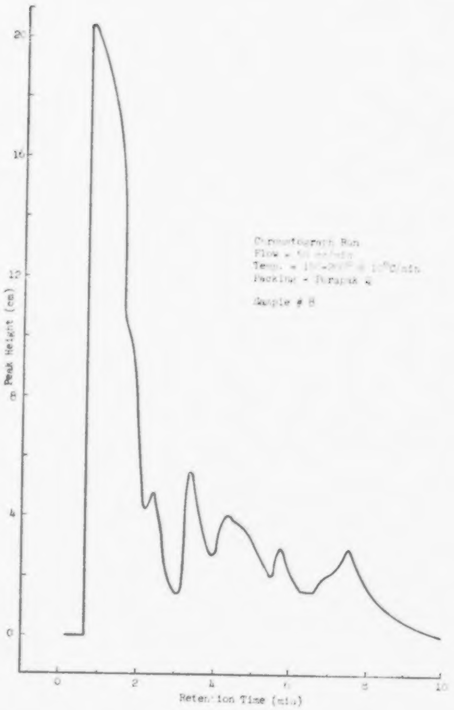


Figure 3

A limited amount of work was done on the gases adsorbed in the last trap. Chromatography showed the presence of at least nine components in this gas. Methane was found in all cases together with carbon dioxide, carbon monoxide, and formaldehyde.

Reaction Runs Using Orgro

The products of reaction obtained in the first trap, which was water cooled, were found to be high viscosity, high-boiling tars. Because of the small quantity and the difficulty of handling, little progress was made in analysis of this fraction.

The second trap which was cooled by ice-water contained a liquid which was over 95% water. The small amount of organic matter present was roughly similar in composition to the material in the third trap. The third trap which was cooled by dry ice-acetone contained the bulk of the organic products. This material was liquid at trap temperatures but also contained dissolved gases which were analyzed.

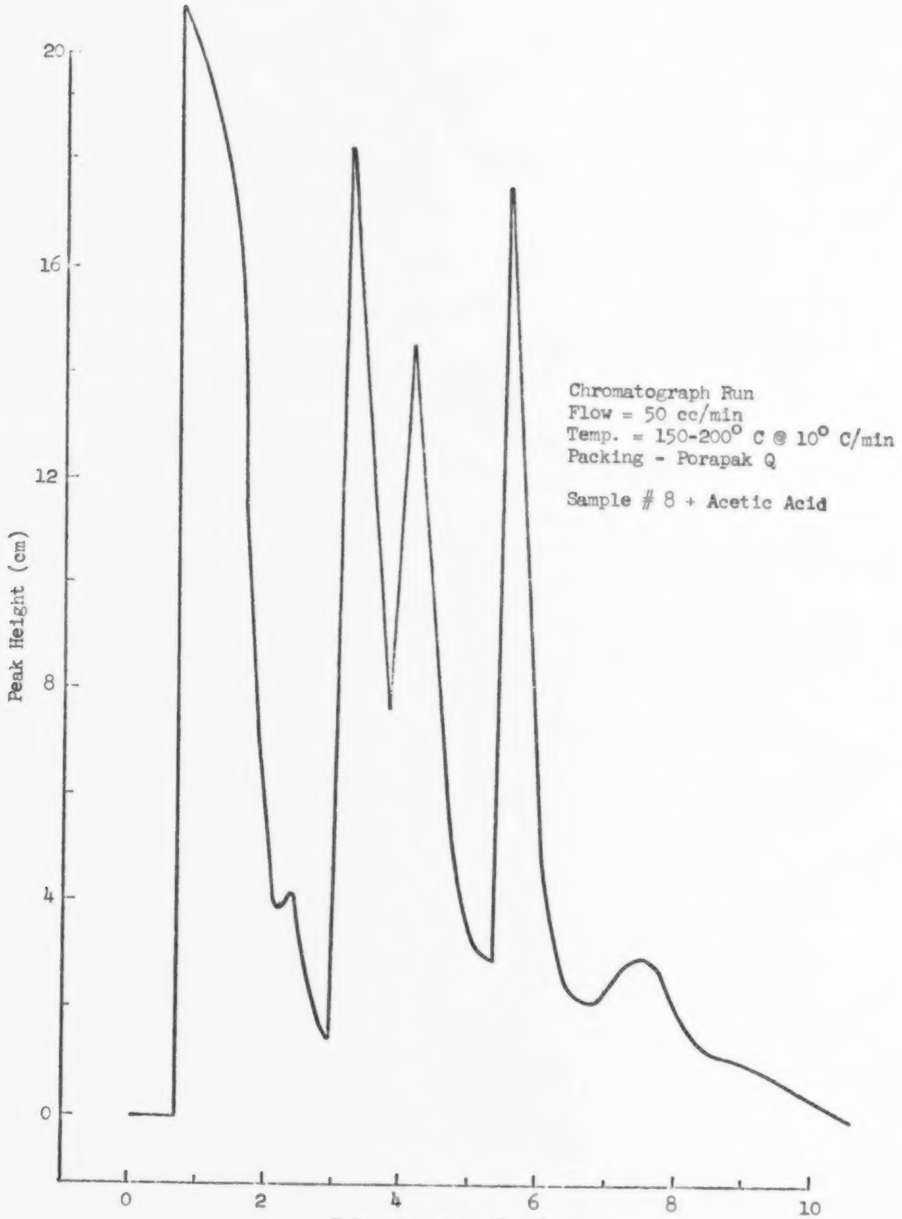
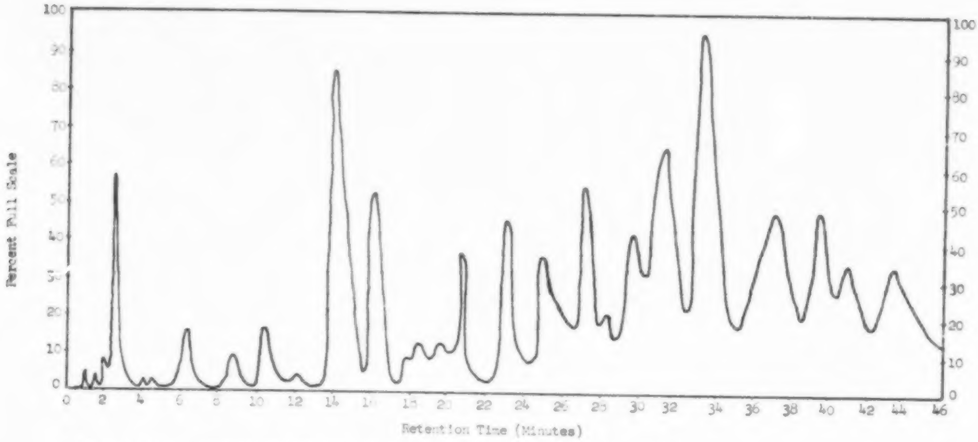

Peak Height (cm)
0
4
8
12
16
20
Retention Time (min)
0
2
4
6
8
10
Chromatograph Run
Flow = 50 cc/min
Temp. = 150-200° C @ 10° C/min
Packing - Porapak Q
Sample # 8 + Acetic Acid

Figure 4



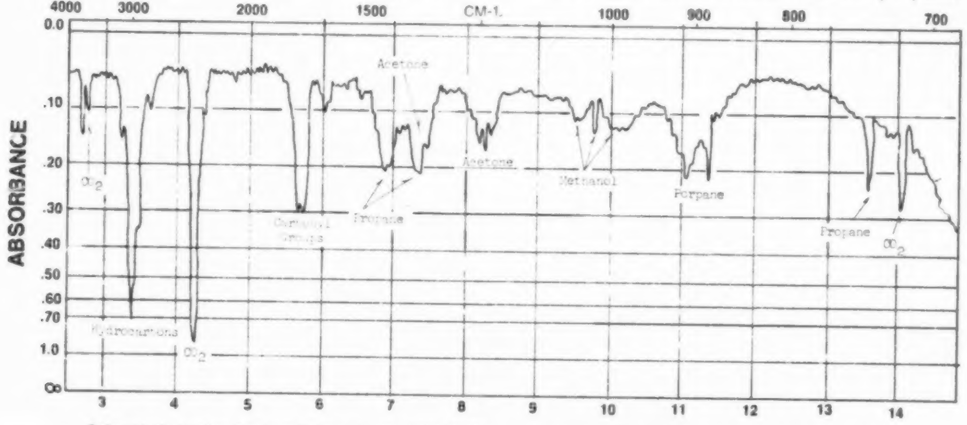
Sample: 1.0 cc. Low-boiling effluents from a partial-oxidation of dried sewage sludge.
Instrument: F & M Model #775 Prepmaster
Analytical Column: 6 feet x ¼ inch stainless steel tubing packed with Porapack Q.
Preparative Column: 80 inches x 3/4 inch stainless steel tubing packed with Porapack Q.
Column Oven: Programmed from 110°C. to 240°C. at 2.5°C./min. and with a post-injection delay of 4 minutes.

Pressure: 50 psig.	Cell Voltage: 100 ma.
Carrier Gas: Helium	Detector Temperature: 251°C.
Detector: Thermal Conductivity	Buffer Zone Temperature: 250°C.
Analytical Flow: 75 ml./min.	Injection Port Temperature: 210°C.
Preparative Flow: 350 ml./min.	Manifold Temperature: 210°C.

Figure 5

A chromatogram of the separation obtained using the preparative gas chromatograph is shown in Figure 5. This sample was from the organic layer collected in the dry ice-acetone trap from the partial oxidation of Orgro. Not all of the eluted peaks have been shown. The components collected in the preparative unit traps were those at retention times of 14, 16, 33 and 37 minutes. These fractions were then run on an infrared unit. A typical spectrum is shown in Figure 6.

The results under partial oxidation conditions indicate the presence of carbon dioxide, propane,



Infrared Absorption Spectrum Using a 10 cm. Path Length Gas Cell of Low-Boiling-Point Partial-Oxidation Effluents Held At 0°C. and Evacuated to 1/3 Atmosphere.

Figure 6

methanol, and acetone. Under conditions of pyrolysis, the products include carbon dioxide, carbon monoxide, methane, ethylene, propane, and ammonia.

Studies with Leaves

As shown in Table 4, both partial combustion and pyrolysis runs were made using a feed of a fluidized mixture of dried leaves and glass beads at temperatures in the range of 250°C-300°C. In addition, pyrolysis runs in the range of 500°C-1000°C were made. Attempts to make high temperature partial oxidation runs were not successful because of the extremely fast reaction which became virtually an explosion. It was almost impossible to collect product samples under these conditions.

TABLE 4
Summary of Leaf Reaction Runs

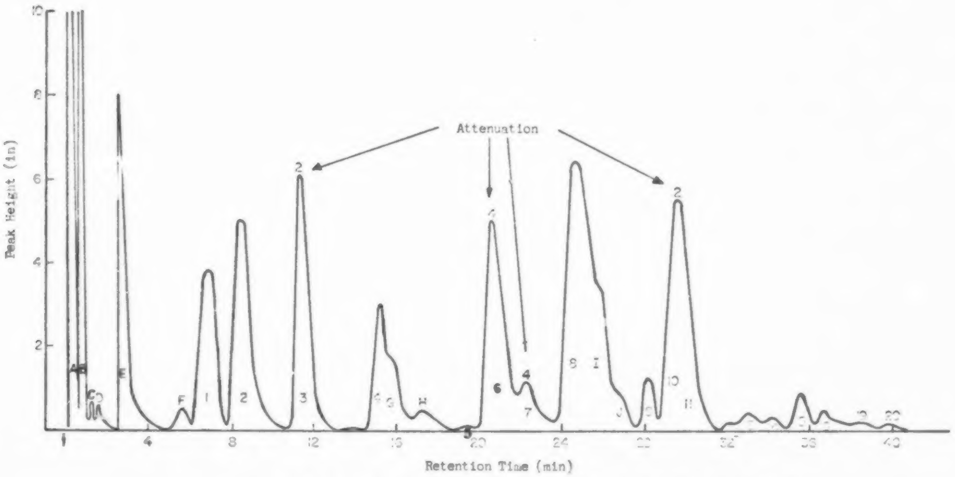
Sample No.	*Sample Size Grams*	*Air:N$_2$ Ratio*	*Residue Grams*	*Liquid Products Grams*	*Temp. °C*
1	136.8	0	85.6	2.3	250-300
2	142.3	0	94.0	7.4	250-300
3	155.0	1:1	90.3	3.8	250-300
4	168.0	1:1	99.2	5.0	250-300
5	62.1	0	23.4	6.2	500-1000
6	73.2	0	25.1	6.9	500-1000

The sample, whose chromatogram is shown in Figure 7, will serve as an example of the application of the syringe reaction technique to the identification of products. This sample was obtained from the pyrolysis of leaves at 250°C-300°C and the results are similar to other runs. In Table 5 is listed the identification of the peaks shown in Figure 7 resulting from the syringe reaction technique.

TABLE 5
Identification of Chromatogram Peaks for Pyrolysis of Leaves at 250°C-300°C
(see Figure 7)

Peak	*Material*
A,B,C,D	unknown
E	water
F,1	unknown
2	methanol
3	formaldehyde
4	an ester
G,H,5	unknown
6	acetaldehyde
7	acetone
8	methyl acetate
I,J,9	unknown
10	ethyl vinyl ether
11-20	unknown

NOTE: Peaks identified by numerals were considered in the analysis; those designated by letters were not involved in identification.



Type of Sample: pyrolysis of leaves before exposure to atmosphere
Volume of Vapor Sample Injected: 10 cc
Type of Reagent: none
Volume of Reagent: none
Time of Exposure: none

Figure 7

Discussion

Examination of the chromatograms made on samples of all materials studied shows many similarities for total combustion, partial combustion, and pyrolysis runs. It appears that many of the same products are present in all cases but in different proportions.

It is felt that the condition of the reactor wall may have had an effect upon the combustion reactions, particularly with regard to the kinetics. It was observed that the wall surface tended to flake and may have influenced the reaction. This is consistent with observations by Albright.[5] It was noted that the time required for a batch reaction decreased for subsequent runs under similar conditions provided that no alterations were made to surface conditions. Carbonaceous deposits tended to accumulate, probably the result of polymerization of products formed. These deposits may well have had a catalytic effect on subsequent reactions.

SUMMARY AND CONCLUSIONS

It appears that a considerable potential exists for reforming the organic portion of a number of solid waste materials into lower molecular weight compounds having significant economic value. The process of partial combustion, which utilizes less than the amount of air required for complete combustion, is effective in reforming paper, the organic portion of a dried sewage sludge, and dried leaves.

It was found that fluidization was an effective technique for bringing finely divided solid waste material into contact with the desired air-nitrogen mixture. In these studies, pyrolysis in which no air was used, was considered to be a limiting case of partial combustion. In cases where the organic waste material was very finely divided, the presence of an inert solid, such as sand or glass beads, helped to stabilize the fluidized bed and minimized channeling or slugging.

Four broad classifications of products were obtained from the reactions, namely: 1) tars, 2) an aqueous mixture, 3) an organic fraction, and 4) a mixture of gases. Tars represented a relatively small portion of the total products formed, and decreased with increasing temperature. Products contained in the tars were not identified. The aqueous fraction was largely made up of water plus water soluble organics. The organic fraction contained a complex mixture of at least 35 materials including dissolved gases. The gaseous products were materials not condensed at the dry ice-acetone bath temperature. A summary of products identified with reasonable certainty is included in Table 6.

The compounds found in partial combustion runs and pyrolysis runs were remarkably similar. As a generalization, oxygenated compound predominated in partial combustion runs, and hydrocarbons predominated in pyrolysis runs.

TABLE 6
Summary of Identified Reaction Products

Paper	*Orgro*	*Leaves*
Water	Water	Water
Acetic Acid	Methanol	Carbon Dioxide
Formic Acid	Acetone	Carbon Monoxide
Formaldehyde	Toluene	Formaldehyde
Methanol	a Nitrile	Methanol
Methane	Propane	Acetone
Carbon Dioxide	Methane	Acetaldehyde
Carbon Monoxide	Carbon Dioxide	Methyl Acetate
Propylene	Carbon Monoxide	Ethyl Vinyl Ether
Ethylene	Ethylene	
Hydrogen	Ammonia	
	Ammonium Carbonate	

The problems of chemical separation and analysis were formidable and many products known to be present remained unidentified. The techniques used included wet chemical methods, gas chromatography in conjunction with peak attenuation and syringe reaction techniques, infrared spectroscopy, and mass spectroscopy.

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REFERENCES

1. Kaiser, E. R., C. D. Zeit, and J. B. McCaffery, "Municipal Incinerator Refuse and Residue," *Proceedings of 1968 National Incinerator Conference* (1968) pp. 142-153.

2. Dimitri, M. S., R. P. Jongedyk, and H. C. Lewis, "Distillation of Fluidized Hardwood," *Chemical Engineering*, December 1948, pp. 124-125.

3. Morgan, L. W., G. M. Armstrong, Jr., and H. C. Lewis, "Distillation of Hardwood in a Fluidized Bed," *Chemical Engineering Progress*, 49, 2 (1953) pp. 98-101.

4. Hoffman, D. A. and R. A. Fitz, "Batch Retort Pyrolysis of Solid Municipal Wastes," *Environmental Science and Technology*, 2, 11 (1968) pp. 1023-1026.

5. Albright, L. F. "Partial Oxidation of Light Paraffins," *Chemical Engineering*, 74, 15 (1967) pp. 197-202.

6. Feldstein, M. "The Colorimetric Determination of Formaldehyde and Methanol from Combustion Sources," Symposium on Air Pollution Control, ASTM Special Technical Publication No. 281 (1960), pp. 23-26.

7. Hoff, J. E. and E. D. Feit. *Anal. Chem.*, 36, 6, 1002 (1964).

8. Burnell, L. K. "Pyrolysis and Partial Oxidation of Leaves," M. S. Thesis Rensselaer Polytechnic Institute, Troy, New York, Sept. 1966.

9. Gilbert, J. S. "Analysis of the Products Formed in the Partial Oxidation of Dried Sewage Sludge," M. S. Thesis, Rensselaer Polytechnic Institute, Troy, New York, June 1969.

10. Maziarz, E. F. "The Partial Combustion of Paper Wastes," M. S. Thesis, Rensselaer Polytechnic Institute, Troy, New York, June 1967.

Pyrolysis-Combustion of Organic Wastes

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and
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INTRODUCTION

Pyrolysis is defined as "chemical decomposition by the action of heat" and refers usually to chemical decomposition of organic materials heated in an environment having insufficient oxygen for combustion. Pyrolysis has a long history in wood distillation and coal coking operations, and today it is practiced, for example, in petroleum refining as well as in coal coking. Coal gasification holds considerable promise for large scale commercialization within the next few years.[1] The extensive literature on thermal degradation, and the number of papers concerning the subject presented at this conference, attest to the current interest in pyrolysis. This paper presents a concept for disposal or utilization of organic wastes by a pyrolysis-combustion process, and discusses the current status of a study being carried out to demonstrate the feasibility of the process.

Pyrolysis-combustion is being developed with the ultimate goal of reclaiming a large fraction of organic material from organic wastes and turning them into useful products or fuels for energy. The term pyrolysis-combustion was employed to describe the process of pyrolyzing waste materials to produce gases, then burning the gases to supply energy to support pyrolysis, and then producing additional energy with the excess gases. Variations of this process are possible, e.g., pyrolysis followed by limited combustion to raise temperature for completion of pyrolysis and then combustion of the final pyrolysis gases. This can provide attractive alternatives to conventional incineration. For example, physical separation of the pyrolysis and combustion steps can provide flexibilities not possible in conventional incineration practices. Gaseous fuels produced by pyrolysis can be processed before burning to remove particulate and selected gaseous components, thus reducing air emissions and eliminating elaborate control equipment in the effluent stream. Moreover, gaseous fuels facilitate maximum control of combustion variables, such as fuel and oxygen mixing and fuel to oxygen ratio, which are important considerations in designing a process to minimize production of unburned hydrocarbons, aldehydes, aromatic hydrocarbons, and similar compounds with air pollution significance.

Pyrolysis-combustion can be designed for utilization of solid waste by recovering valuable organic materials from various points in the process flow. In our work this development has been subordinated to developing the process for disposal of organic matter with the production of energy. This phase of the study could also involve development and use of catalysts to promote desired reactions. Removal of products from a process stream for recovery of organics could involve absorption, extraction, distillation, or other suitable isolation procedures. Material not recovered could be returned to the pyrolysis-combustion system for further processing.

Processes are being developed to classify and segregate various materials in solid waste management. The emphasis being placed upon sorting, size reduction, and classification of solid waste indicates that organic waste material will soon be processed to desired compositions, sizes, and densities, thus allowing optimum feed conditions for pyrolysis-combustion.

According to Kaiser,[2] typical municipal refuse contains about 59% paper and paper products, and 14% cellulosic or lignocellulosic matter, for a total of approximately 73% of material which can be classified as lignocellulosic in origin. The remaining refuse is composed of approximately 5% meat scraps and fat, 3% organics (including plastics, rags, leathergoods, rubber composition, and paint and oils), and 19% inorganic matter (including metals, glass, ceramics, and ash). Wastes in rural areas contain a higher percentage composition of lignocellulosic matter because of inclusion of more agricultural residues.

Because the composition of solid wastes varies with their source, it is pertinent to understand how pyrolysis affects waste components and how the components interact. Moreover, it is important to understand pyrolysis of lignocellulose because of its predominance in organic waste matter. Accordingly, some of the important literature on this subject is reviewed.

The progression of pyrolysis when heating a solid piece of wood in the absence of air has been described by Browne.[3] Four distinct zones were observed as temperature was increased. The first appeared at temperatures up to 200°C in which the surface became dehydrated. In addition to water, traces of carbon dioxide, formic acid, acetic acid, and glyoxal were evolved. The second zone appeared when the temperature was between 200 and 280°C. The products evolved in trace amounts in the first zone were now evolved in substantial amounts and the wood slowly became charred. The first zone moved deeper into the wood, and vapor evolved in this zone had to pass over the materials in the second zone. As heating continued and the temperature increased from 280°C to 500°C, a third zone appeared. A highly exothermic reaction took place, and this was accompanied by rapid increase in temperature unless the heat was dissipated. Major products formed in this zone included carbon monoxide, methane, formaldehyde, formic acid, acetic acid, ethanol, and (at the higher temperatures) hydrogen and high molecular weight tars. These degradation products may have undergone further reaction with the carbonaceous residue. Finally, as temperatures increased above 500°C, a fourth zone appeared in which the gaseous products and tars could react with the charcoal to produce highly combustible products. At temperatures above 500°C charcoal undergoes gasification in the presence of water vapor and carbon dioxide to form carbon monoxide and hydrogen. All four zones were still present, but each moved further into the piece of wood as the temperature increased until the final temperature was reached at the center.

Kilzer and Broido[4] discussed their work and that of others in the thermo-gravimetric analysis (TGA) and differential thermal analysis (DTA) of cellulose. Using TGA it was possible to show that cellulose suffered weight loss in three distinct temperature regions. These results correlated with DTA results. Thus, in the first region a slightly endothermic dehydration in the range of 200 - 280°C took place with the formation of dehydrocellulose. The latter then underwent strongly exothermic reactions to form the type of products noted above for this temperature zone. A second more strongly endothermic reaction was initiated at about 280°C, and this resulted in formation of a tar having a high percentage of levoglucosan. Finally, at about 320°C a strongly exothermic region appeared corresponding to the char-forming reaction and the production of a large variety of small carbon containing compounds. Kilzer and Broido showed that inorganic salts present in amounts as low as 0.1% based on the cellulose would appreciably change the pyrolysis so that greater amounts of carbonaceous ash were produced. These inorganic impurities functioned as catalysts in the dehydration char-forming reactions thereby reducing the extent of the depolymerization tar-forming reactions. Lipska and Wodley[5] observed these weight losses using a technique employing a nitrogen-fluidized sand bath as an isothermal pyrolysis chamber. Weight loss of cellulose samples treated with potassium bicarbonate was seven times that of the untreated sample, but residual carbonaceous residue increased to 34% from 14% for the untreated sample. Thus, this salt increased the reactions involved in formation of dehydrocellulose and its conversion to charcoal. Lipska and Wodley noted that use of their isothermal technique above 360°C to obtain kinetic data was experimentally difficult due to the rapid rate of pyrolysis, and their work indicates that in heterogeneous solid waste the presence of inorganic material would tend to have a catalytic effect on important pyrolysis reactions.

Shafizadeh[6] reviewed the literature on the pyrolysis and combustion of cellulosic materials and neatly summarized the reactions involved. At lower temperatures, dehydration and charring reactions take place; levoglucosan, a principal intermediate, and combustible volatiles are formed at somewhat higher temperatures and are involved in flaming combustion. In discussing physical variables affecting pyrolysis and combustion, diffusion of heat up to a certain radiant exposure was the governing factor. Above a certain value of radiant exposure, convective heat losses or convective mixing become increasingly important, and a calculation of rate based on diffusivity alone is not valid. Duration of radiation will affect the result, and the criterion for ignition is the attainment of a surface temperature in the order of 600°C. Similar principles should apply to pyrolysis in the absence of oxygen, and should be important considerations in the design of a pyrolysis unit. Flash pyrolysis with high irradiance levels for periods up to 8 seconds produced mainly tar, carbon monoxide, carbon dioxide, and water. However, isothermal pyrolysis at 370°C for longer periods of time produced large quantities of secondary reaction products composed of a wide array of organic compounds. These results support the observations of Martin concerning reactions taking place in the four temperature zones.

Background Studies in Pyrolysis of Kraft Black Liquor

In our studies, a commercial kraft black liquor concentrated to 50% solids was pyrolyzed by batch[7] and steady-state[8] pyrolysis. The liquor used comprised approximately 21% sodium, 3.8% total sulfur, and 73% as organic components dissolved from wood. These components contain approximately 35% as alkaline lignin, 30% as degraded carbohydrate products, and 8% solubilized extractives. In the batch pyrolysis study, black liquor was evaporated to solids and the vessel and its contents brought to temperature over a period of two hours; during this time volatile products were continuously removed. In steady-state pyrolysis, concentrated black liquor was sprayed at a predetermined rate into the reaction vessel which was held isothermally at a predetermined temperature. Comparison of these two studies[9] over a temperature range from 400 to 1135°C showed a several-fold increase in the volume of uncondensed gases formed in the higher temperature ranges in steady-state pyrolysis. The high hydrogen content of the gas, and the fact that weight of the gas produced was greater than total weight of organic matter present in the kraft black liquor solids used in the steady-state experiments conducted above 950°C, plus the fact that organic carbon in the residue decreased almost linearly from 22% at 600°C to 2.5% at 1135°C, were all considered good evidence for the occurrence of the steam-char reaction ($C + H_2O \rightarrow CO + H_2$) under the conditions of pyrolysis. However, because of short residence time, equilibrium may not have been achieved.

Methane, present in low concentrations in both types of pyrolysis, may be attributed to cracking of complex molecules to simple hydrocarbons. Under the conditions of pyrolysis, methane is not expected to form by the hydrogen-char reaction ($2H_2 + C \rightarrow CH_4$), but it is expected that the methane reformation reaction ($CH_4 + H_2O \rightarrow CO + 3H_2$) controls the concentration of methane. A summation of calorific values of the major steady-state pyrolysis products isolated from black liquor, when compared to the calorific value of the original black liquor solids, showed the over-all system to be endothermic.

In both batch and steady-state studies, adaptation of microcoulometric titration for analysis of hydrogen sulfide, coupled with quantitative reduction of organically-bound sulfur to hydrogen sulfide in a stream of hydrogen, provided a sensitive specific method for quantitative determination of sulfur in this case (where chlorine compounds were generally absent). When this system is used as the detector for a gas chromatograph, it is possible to detect and quantitatively determine the sulfur present in each component as it is eluted from a chromatographic column.[10] In the batch pyrolysis study, the presence of over 23 sulfur-containing products was demonstrated. By a substantial improvement in instrumentation used in the steady-state study, the presence of over 57 sulfur-containing products was demonstrated.[9] Production of the major sulfur-containing components, methyl mercaptan and dimethyl sulfide, as well as the minor sulfur-containing components, was shown to be strongly affected by temperature and to steadily decrease as temperatures were increased above 600°C. Formation of hydrogen sulfide, however, reached a maximum between 700 to 800°C It was concluded that above 600°C organic sulfur-containing products were decomposed to produce hydrogen sulfide and sulfur-free organic degradation products in the reducing atmosphere sustained in pyrolysis. The sharp decrease in the hydrogen sulfide present at a temperature above 850°C can be attributed, in part, to change in equilibrium for the reaction of hydrogen sulfide and sodium carbonate to form sodium sulfide, carbon dioxide, and water. An alternative explanation is that the surface area for the reaction of hydrogen sulfide was significantly reduced when the ash formed smelt above 850°C. Maximum concentrations of organic sulfur-containing products formed in batch pyrolysis in the range of 500 to 600°C were attributed to the removal of these materials as they formed. Dimethyldisulfide formation appeared to be due to dehydrogenation of methyl mercaptan. The increase in hydrogen sulfide throughout the temperature range in batch pyrolysis could be attributed to its removal from the reaction zone as it was formed.

A dual-channel technique for the detection of organic pyrolysis products has been developed[11] in which the stream eluting from a chromatograph is split, with one portion directed to a flame ionization detector (FID) and the other portion to the microcoulometric titration (MCT) system. Using this technique it was shown that, in chromatograms obtained using FID, the responses due to sulfur-containing products were masked by the responses due to sulfur-free organic products present in greater amounts. The sulfur-free organic products were isolated from the organic liquid pyrolysis phase in sufficiently high purity by preparative gas chromatographic techniques so that reliable mass spectra of the isolated compounds could be obtained. Compounds identified included benzene, toluene, m- and/or p-xylene, Anisol, Phenol, O-cresol, m- and/or p-cresol, 2,5- and/or 2,4-dimethyl phenol, 3,5-dimethyl phenol, 2,3-dimethyl phenol, and 3,4-dimethyl phenol. Identification of the last two compounds has been by gas chromatographic techniques only and is therefore tentative.

Because sulfur-containing organic products were present in relatively minor amounts in the organic liquid pyrolysis phase, a method of separation of these products from the sulfur-free products was necessary. This separation was effected by treatment of an ether solution of the organic pyrolysis products with mercuric chloride in 95% ethyl alcohol. Mercury complexes of the sulfur-containing products were precipitated and isolated. These products were then regenerated by treatment of the precipitate with hydrogen sulfide in a binary ether-water system. On gas chromatographic analysis of the recovered sulfur-containing products in ether using the dual detection system, positive correlation of responses using FID were made with responses using MCT. Identification of major sulfur-containing products obtained in pyrolysis will continue to be part of our study.

Comparison of products formed in steady-state pyrolysis at 1135°C with those formed at 750°C demonstrated the drastic reduction in all sulfur-containing products and all but a few relatively high-boiling sulfur-free products.

A concept based upon results obtained in batch and steady-state pyrolysis was presented[12] to explain the production of malodorous products in kraft recovery furnaces. According to this concept, thermal degradation of complex organic fuel to less complex organic structures and simple free radicals progresses as temperature is increased. At temperatures below about 750°C, the free radicals including simple carbon fragments, those containing sulfur, atomic hydrogen, atomic oxygen, hydroxyl, and hydroperoxy would be expected to be present. These may recombine on cooling to form the wide array of products obtained in pyrolysis at lower temperatures. However, as temperatures are increased, pyrolysis products, given sufficient residence times, will form thermally stable products, including hydrogen, carbon monoxide, carbon dioxide, and methane. Although methane does increase with temperature, its concentration, as noted above, would be controlled by the methane reforming reaction. Thus, temperature and time — two of the four controlling parameters in combustion — can be controlled in pyrolysis to maximize production of simple gases.

Design of a Pyrolysis-Combustion System

With the literature and experimental background outlined, the design of a pyrolysis-combustion system was undertaken. The basic concept is simple. Organic matter, either a liquid such as kraft black liquor or a solid organic waste, is introduced into a pyrolysis zone. In the pyrolysis zone (which may comprise one or more stages), organic matter is subjected to a sufficiently high temperature long enough to pyrolyze and gasify the organic solids. Inorganic matter is converted to an ash or smelt, and provisions must be made for its removal. The pyrolysis gases are cooled, processed to remove specific components, and then stored; they can then be burned on demand to supply heat to the pyrolysis process, with excess being used in power generation.

To carry out pyrolysis studies, and to determine the feasibility of applying pyrolysis-combustion to organic wastes, an experimental unit was designed and built to pyrolyze both liquid and solid waste. One important consideration was the maximum temperature to be achieved. The kraft black liquor studies indicated that this temperature should be in excess of 1000°C in order to minimize production of undesirable products. This temperature would also be adequate to convert a large fraction of most organic wastes into hydrogen, methane, carbon monoxide, and other gases which are desirable fuels. The problem arose as to how to reach this temperature and maintain necessary heat transfer while limiting corrosion. Thermal conductivity properties of metals are favorable for transference of heat through a reactor wall, but the most corrosion-resistant metals cannot withstand the corrosive effects of alkaline kraft black liquor at temperatures above 750°C. On the other hand, ceramic materials which have excellent corrosion-resistant properties have very low values of thermal conductivity.

The antithetical requirements for attaining high temperature and corrosion resistance were resolved by resorting to a two-stage pyrolysis design. This was the simplest of a more general multistage design concept wherein metal is used for the first low-temperature stages to facilitate heat transfer through reactor walls, and ceramic material is used in the later stages for corrosion resistance. In the first stages, water evaporates from the waste material and pyrolysis begins. In the later stages, pyrolysis is completed with a portion of the necessary heat being supplied by conduction through the ceramic walls which are heated by an external source. However, the bulk of the heat must be provided by some other method. Of various heating methods visualized, the one chosen for initial study involves limited oxidation by adding a controlled amount of heated air.

Two-Stage Pyrolysis-Combustion Experimental Unit

In keeping with the interests of this conference, the two-stage experimental unit which was designed and built will be described from the viewpoint of processing solid waste.

The unit consists of an outdoor structure on a concrete pad. A 2-story, metal frame supports the first stage pyrolysis unit and auxiliary equipment. The major equipment items are the first and second stage pyrolysis reactors. These may be considered fixed equipment around which the auxiliary equipment can be arranged in various configurations to develop the most suitable process designs. The figure shows a schematic of the equipment.

In initial solid waste studies, it is planned to use a bottom-feed operation in the first stage. Equipment for this includes a solid waste hopper, a ram feeding-system, a hot gas fan, a cyclone, and appropriate transfer lines. Feed will be injected into a stream of recycled pyrolysis gas in the bottom of the first reactor. The hot gas will initiate evaporation and carry the solids into the heated zone of the vessel. Within the vessel is a fluidized or pneumatically conveyed bed of solid particles undergoing pyrolysis. Velocity of the gas stream is adjustable and will be an important parameter in the initial studies.

The first reactor is 8" in diameter and 6' in length and is constructed of stainless steel (type PH 15-70 MO), having high corrosion resistance to a reducing type environment. The top and bottom are flanged to facilitate changes in feed and product removal configurations. Five thermocouples located at equally spaced vertical intervals will record reactor temperatures. Two gas burners located in an annular space around the reactor will provide the necessary heat to the reactor. The gas flow to the burners is regulated by a temperature indicator-controller system (Versatronik).

Particulate matter suspended in the gas stream leaving the top of the first reactor will be separated out in the cyclone and fed to the top of the second reactor. This L-shaped reactor has a 6' by 9" by 12" vertical section and a 6' by 9" by 18" horizontal section formed of alumina castable ceramic material durable to 3400°F. This material can withstand extreme temperature conditions in an alkaline environment (important to the kraft black liquor studies), and, because of its very low iron content, is resistant to carbon monoxide disintegration. The floor of the horizontal section slopes toward the residue port leading to the residue tank. The side walls of the reactor are heated by gas burners located in combustion chambers on each side of the L-shaped chamber. The gas flow to the burners is regulated with a control system similar to that for the first reactor.

Gases and residue are discharged from the second-stage reactor to a tank where residue is collected and allowed to cool. Gases are discharged from the tank directly to a pyrolysis gas burner for flaming.

The figure indicates temperature, pressure, and gas flow sensors. The recorders for these instruments, and the control panels for operation of the experimental unit, are contained in an 8' by 12' building adjacent to the unit. Cabinets house the air blowers and the liquid-waste feed pumps. Sampling ports are located at the top of the first-stage pyrolysis reactor, in the transfer system between the first and second pyrolysis stages, at the discharge end of the second pyrolysis stage, in the residue tank, in the transfer line between the residue tank and pyrolysis gas burner, and at two points in the pyrolysis gas burner.

This equipment configuration will be used in initial studies planned to begin as soon as equipment shakedown procedures are completed. With the present equipment it should be possible to remove some of the pyrolysis gases from the first reactor for the processing which will separate organic chemicals of commercial value.

CONCLUSIONS

Pyrolysis studies to date have shown that a relatively simple gas can be produced from organic material by high temperature pyrolysis. This gas can then be cleaned of potential air contaminants before combustion.

Pyrolysis-combustion has potential for recovery of commercially valuable organic materials from organic wastes. Better understanding of pyrolysis mechanisms and their control are required before the full potential is known.

Methods have been developed to identify many pyrolysis products, and this continues to be part of our research effort.

An experimental unit has been designed to further study pyrolysis mechanisms and to determine technically and economically feasible designs of process and equipment for applying pyrolysis-combustion to organic waste materials.

ACKNOWLEDGEMENTS

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REFERENCES

1. "Fuel Gasification," Advances in Chemistry Series 69: preface (1967), ed. F. C. Schora, Jr.

2. Kaiser, E. R. *Proceedings of the 1966 National Incinerator Conference*, Incineration Comm., Process Industries, Div. of ASME, New York, 1966.

3. Browne, F. L. U. S. Dept. Agr. Forest Prod. Lab. Mimeo No. 2136, December 1958.

4. Kilzer, F. J. and A. Broide. *Pyrodynamics*, 2 (1965) pp. 151-163.

5. Lipska, A. E. and F. A. Wodley. USNRDL-TR-68-89, 22, March 1968 (UNCLAS).

6. Schafizadeh, F. *Adv. in Carbohydrate Chem*, 23 (1968) pp. 419-474.

7. Feuerstein, D. L., J. F. Thomas, and D. L. Brink. *Tappi*, 50, 6 (1967) pp. 258-262

8. Jones, K. H., J. F. Thomas, and D. L. Brink. *Journal Air Poll. Control Assn.*, 19, 7 (1969) pp. 501-504.

9. Brink, D. L., J. F. Thomas, and K. A. Jones. *Tappi* (in press, tentative publication, 53 (May 1970)).

10. Brink, D. L., J. F. Thomas, and D. L. Feuerstein. *Tappi*, 50, 6 (1967) pp. 276-285.

11. Brink, D. L., A. A. Pohlman, and J. F. Thomas. Preprint, 55th Annual Meeting TAPPI, Feb. 15-19, 1970, New York.

12. Thomas, J. F., K. H. Jones, and D. L. Brink. *Tappi*, 52, 10 (1969) pp. 1873-1875.

Hydrogenation of Municipal Solid Waste With Carbon Monoxide and Water

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During an investigation of the mechanism of lignite liquefaction with carbon monoxide and steam, it was discovered that cellulose and other carbohydrates could also be converted to a heavy oil.[1] The composition of municipal refuse varies considerably, depending upon the location and time of year, but the major constituents, by a considerable margin, are almost always carbohydrates. These include food wastes, which are actually a minor component, and a variety of cellulosic wastes such as those shown in Table 1. After removing the moisture, metals, and siliceous materials, the carbohydrate content is usually above 90 percent. It was therefore clear that the techniques developed for lignite and carbohydrate liquefaction should be applicable to the solid waste problem.

Other investigators have also been successful in converting cellulosic materials to an oil or bitumen by chemical means. The bitumens in these cases are low-melting solids. Foremost among the early researchers was Berl (Table 2). Berl was

TABLE 1
Sample Municipal Refuse Composition — U.S. East Coast

Cardboard	7%	Moisture	28.0%
Newspaper	14	Carbon	25.0
Miscellaneous paper	25	Hydrogen	3.3
Plastic film	2	Oxygen	21.1
Leather, molded plastics, rubber	2	Nitrogen	0.5
Garbage	12	Sulfur	0.1
Grass and dirt	10	Glass, ceramics, etc.	9.3
Textiles	3	Metals	7.2
Wood	7	Ash, other inserts	5.5
Glass, ceramics, stones	10		100.0
Metallics	8		
Total	100		

Source: Kaiser, E. R., "Refuse Reduction Processes," in "Proceedings. The Surgeon General's Conference on Solid Waste Management for Metropolitan Washington." U.S. Public Health Service Publication No. 1729, Government Printing Office, Washington, D.C., July 1967, p. 93.

very enthusiastic about the possibilities of using cellulose as a source of petroleum products and his work covered more than a decade (Table 3). According to Berl, about 4 percent of our arable land planted in sugar cane could have supplied our petroleum needs in 1940. Today, the required acreage would be three times greater. The problem was that an economically feasible method of converting cellulose to oil was not available. Berl's work was continued by Heinemann (Table 4), who worked out the process conditions and determined the yields of petroleum-type fractions available from sugar cane.

TABLE 2

E. Berl, Naturwissenschaften 20, 652 (1932)

$$\text{Vegetable Matter} \xrightarrow[\text{5 hr. 350° C.}]{\text{aqueous alkali}} \text{Bitumen + Water + Gas}$$

TABLE 3

E. Berl, Science 99 309 (1944)

$$\text{100 tons bagasse} \xrightarrow[H_2O]{NaOH} \text{150 barrels protoproduct}$$

$$\text{150 barrels protoproduct} \xrightarrow{H_2} \begin{array}{l}\text{2,550 gal. gasoline}\\ \text{2,950 gal. middle oil}\\ \text{1,020 gal. lube oil}\end{array}$$

TABLE 4

H. Heinemann, Petroleum Refiner 29 Vol. No. 2, 111 (1950)
33 Vol. No. 7, 161 (1954)
33 Vol. No. 8, 135 (1954)

$$\text{sugar cane + 1 N NaOH} \xrightarrow[\text{250°F}]{\text{5 hr.}} \xrightarrow[\text{650°F}]{\text{5 hr.}} \begin{array}{l}\text{CO 18.4\%}\\ \text{CH 3.0\%}\\ \text{Bitumen 50.6\%}\\ \text{Water 26.8\%}\end{array}$$

$$\text{Bitumen} \xrightarrow[H_2]{Mo_2O_3} \begin{array}{l}\text{Gasoline (8.2\%) + Naphtha (11.4\%)}\\ \text{+ Gas Oil (44.4\%) + Heavy Oil (15.4\%)}\\ \text{+ Asphalt (20.6\%)}\end{array}$$

Table 5 shows the relationship between crude oil production and solid waste collection. Assuming a barrel of oil per ton of refuse, 5 percent of our petroleum needs are available from urban wastes. The barrel per ton estimate is based on refuse containing approximately 50 percent dry organic matter. If we add the cellulose available from the paper pulp and wood products industry, another 5 percent of our crude oil production is potentially available.

TABLE 5

Statistical Abstract of the U.S. (U. S. Bureau of the Census: 1969) Washington, D.C. 1969

Crude Oil Production in U.S., 1969	3.3×10^9 barrels
Gasoline Production in U.S., 1969	1.8×10^9 barrels
Solid Wastes Collected in 1969	2×10^8 tons

The composition by weight of two sources of refuse used in our work is given in Table 6. The source of the refuse did not appear to have a significant influence on the results and nearly all of the experimental work was conducted on the Altoona refuse. This material was obtained from a small plant of the Fairfield Aerobic Mulch Corporation near Altoona, Pa. The refuse arriving at plant is separated by the householders in the area into a metal and glass-free fraction to be composted at the plant. It is moistened and shredded prior to bacterial digestion. Our material is taken from a moving belt leaving the shredder. It has more moisture than most other refuse because of the wet shredding process. The sampled refuse is stored in plastic bags under refrigeration until needed in the laboratory.

Visual examination indicated the refuse to be predominately cellulosic. The only other obvious items were polyethylene film and small amounts of polystyrene foam and aluminum foil. The relatively high nitrogen content of the product and the presence of palmitic and stearic acids suggested that more than traces of animal matter were present in the sampled refuse, but this was not revealed by visual examination.

Although some degradation of the polyethylene occurred, most of this and other plastic materials are believed to be relatively inert, espe-

TABLE 6

Composition of Refuse (Metal- and Glass-Free)

Source	*Altoona, Pa.*			*Madison, Wis.*		
Composition, %/wt.	*As received*	*Dry*	*daf*	*As received*	*dry*	*daf*
C	34.7	49.9	58.3	35.1	38.7	55.1
H	7.4	5.8	6.8	5.7	5.1	7.3
N	0.7	1.0	1.1	0.5	0.6	0.8
O	47.0	28.6	33.5	31.6	25.7	36.6
S	0.2	0.3	0.3	0.1	0.1	0.2
Ash	10.0	14.4	-	27.0	29.8	-
Moisture	30.6	-	-	9.4	-	-
Volatile matter	50.2	72.3	84.5	51.8	57.2	81.4
Fixed carbon	9.2	13.3	15.5	11.8	13.0	18.6
Btu/lb	5670	8170	9540	5790	6390	9110

cially in the low temperature work, and become part of the unconverted residue. It is expected that this residue can be utilized as a solid fuel. The fate of plastic has not yet been studied in detail, but these materials do not appear to be a problem.

This work was conducted in 500-ml and 5-liter stainless steel autoclaves fitted with a rocking mechanism to supply agitation. The Altoona refuse contained enough water and naturally-occurring catalytic agents so that only refuse and carbon monoxide were charged to the autoclave in the experimental work at high temperatures and pressures (380°C, 5,000 psig). Recent work at milder conditions (250°C, 1,500 psig) was conducted in the presence of additional water and catalysts at both the severe and the mild conditions.

In the laboratory, the product oil is most easily recovered by extraction with benzene or acetone. The solvent is then stripped off, first at atmospheric pressure and then under vacuum in order not to overheat the product. Benzene is a good solvent for the oil formed above 350°C, but acetone is the preferred solvent for the product formed at lower temperatures. On a larger scale, distillation or distillation plus mild pyrolysis may be a preferred method for recovering the oil. These latter methods result in a less viscous oil than that obtained by extraction, but the yield is lower.

If cellulose is heated above 250°C in the absence of carbon monoxide, dehydration and decarboxylation occur, and the major product is a char. If carbon monoxide is present, these reactions still occur, but the extent of the dehydration reaction is decreased and decarboxylation reaction increased. The result of this change in the reaction is an increase in the hydrogen-to-carbon ratio and a change in the physical form of the product from a solid to a heavy oil or low-melting solid. The formation of an oil is also favored by the presence of water and catalysts such as sodium carbonate.

Hydrogen also directs the conversion of cellulose to oil but is considerably less effective than carbon monoxide. Table 7 illustrates the relative effectiveness of carbon monoxide and hydrogen in converting cellulose to a benzene-soluble oil in the absence of catalysts. The oil obtained in the presence of hydrogen in 5 percent yield has a high H/C ratio, but the high oxygen content of this oil suggests that some of the hydroxy groups of the original material are still present.

Table 8 illustrates the greater effectiveness of carbon monoxide over hydrogen in the conversion of Altoona refuse to oil. Naturally-occurring catalysts are undoubtedly present in this system. Thirty to 40 percent of the carbon monoxide charged to the system was converted to hydrogen and carbon dioxide by the water-gas shift reaction. Some of the hydrogen formed is believed to hydrogenate the cellulose decomposition products. Molecular hydrogen, however, is significantly less effective than carbon monoxide and water. This is taken as evidence that activated hydrogen coming from the water-gas shift reaction may be responsible for the greater effectiveness of the carbon monoxide and water. It is also believed that carbon monoxide has a unique effect, as yet undefined, in directing the conversion of cellulose to oil.

TABLE 7
Composition of Benzene-Soluble Products
and Residue from Cellulose
(2 hr. at 350°C, 1500 psig initial pressure)

	Benzene-soluble product		*Residue*	
	$CO + H_2O$	$_2$	$CO + H_2O$	H_2
Wt. % of charge	40.0	5.0	10	40
C (%)	83.3	76.3	71.4	74.9
H (%)	7.8	8.2	5.9	4.6
O (%)	8.9	15.5	12.7	20.5
H/C mole ratio	1.11	1.27	0.98	0.73

TABLE 8
Conversion of Municipal Refuse to Oil
(20 min. at 380°C, 1500 psig initial pressure)

Gas	CO	H_2
Conversion, %/wt.	94	80
Product distribution, %/wt.		
Oil[a]	41	18
Residue	6	20
Water	27-36	45
CO_2	15-24	15
Other	2	2

[a] Composition: C, 79.6%; H, 9.5%; N, 1.9%; S, 0.13%.

The sulfur content of the oil obtained from municipal refuse is approximately 0.1 percent. Because of this low sulfur content, it may be preferable to use the entire oil as a fuel oil, rather than convert it to a broader spectrum of petroleum-type products.

Many of the petroleum residual oils used as industrial fuel oils have sulfur contents greater than one percent and exceed sulfur specifications in some localities. The oil from refuse may find use as a blending agent to reduce the sulfur content of high sulfur petroleum fuel oils.

A nitrogen content of 2 to 3 percent is characteristic of oil obtained from municipal refuse. The nitrogen is not expected to be a problem in fuel oil, but will have to be removed if the oil is to be converted to gasoline. Cellulosic wastes, not contaminated with animal wastes, usually have a nitrogen content of less than 0.5 percent.

Sewage sludge is also readily converted to an oil. The oil obtained from sewage sludge contains a little more sulfur (0.5 to 0.6 percent) and about the same nitrogen as the oil from municipal refuse.

Two major cost items in the conversion of refuse to oil are the capital investment in equipment and the cost of the carbon monoxide. After the feasibility of the conversion of municipal refuse to oil was demonstrated, the research was directed to determining the minimum temperature and pressure conditions at which reasonable conversions could be obtained.

Recent research has shown that conversion of 85 to 90 percent of the organic matter in refuse can be converted to bitumen, a water-soluble fraction, water, and gas at temperatures as low as 250°C and operating pressures near 1,500 psig (Table 9). Water, sufficient to maintain the liquid phase, containing 2.5 to 5.0 percent sodium bicarbonate was used in the low temperature work Although the conversions decreased only slightly the product obtained at the milder conditions has more oxygen and a higher softening point than the product obtained at 380°C (Table 10). The low temperature product is more acetone soluble and less benzene soluble than the high temperature product. Infrared analysis indicates the two products to be similar in composition, largely paraffinic with carbonyl groups. Because of the viscous nature of the low temperature product, it will probably be necessary to treat this material, e.g. by a coking or catalytic hydrogenation step, before it can be used.

TABLE 9

Low Temperature Conversion of Refuse
(1:1 refuse and water, 600 psig initial CO
pressure, 3 hr 260°C)

Conversion	87.5%
Product distribution, %/wt.	
Bitumen	18.5
Residue	12.5
Water soluble	17
Water	35
CO_2	16
Other	1

TABLE 10

Effect of Temperature on Product
(500 ml. autoclave, paper towels charged)

Temp., °C	380	250
Time (hr.)	2	1
Water (ml.)	40	200
Catalyst	None	10 g. $NaHCO_3$
Initial CO pressure (psig)	1500	500
Operating pressure (psig)	5100	1700
Conversion (%)/wt.	77	87
Composition of oil:		
C (%)	83.3	71.7
H (%)	7.8	7.3
O (%)	8.9	21.1
H/C mole ratio	1.11	1.21

The largest difference in product distribution between the high and low temperature products is in the relative yields of water-soluble and acetone-soluble materials. At 380°C very little water-soluble material remains. The work at 250°C in the presence of water in the liquid phase yielded relatively large amounts of compounds resulting from hydrolysis of the cellulose. This aqueous solution may be recycled. The carbohydrate-type materials and carbohydrate derivatives are eventually all converted to oil. The rate of carbohydrate conversion to oil increases with its concentration, and as the concentration builds up because of recycle, an equilibrium is reached in which it appears that all of the carbohydrates charged are converted to oil.

It is also possible that the water-soluble fraction may be a low-cost nutrient for the growth of yeasts capable of producing a high protein animal feed. This possibility has not yet been tested.

Table 11 shows the oil yields available from a number of processes. Urban refuse appears to be competitive. There are some engineering problems to be solved, e.g. methods of pumping the refuse into a unit. The high oxygen and nitrogen contents of the initially formed bitumen may also present problems if this material is to be upgraded to gasoline-type products. These problems appear to be solvable, but will have to be researched. One of our engineering groups at the Pittsburgh Coal Research Center is now constructing a continuous unit to evaluate this process on a large scale.

TABLE 11

Oil Yields from Various Sources

Process	*Yield of Oil*
Fischer-Tropsch	60 gal./ton of coal
Oil shale	40-60 gal./ton of shale
COED	53-63 gal./ton of coal
Urban refuse (metal and glass free)	85-100 gal./ton dry refuse
Coal hydrogenation	125-135 gal./ton bituminous coal

TABLE 12
Favorable Features in Processing Cellulosic Wastes to Oil

1. Mild temperatures + moderate pressures = low capital investment.
2. No hydrogen required. Low CO consumption.
3. Low-cost catalyst, losses small.
4. Low raw material cost.
5. Low sulfur product.

Table 12 summarizes the favorable features of the oil from refuse process. This research is continuing with the emphasis on improving the technology and understanding of the low temperature process.

REFERENCES

1. Appell, H. R., I. Wender, and R. D. Miller. *Chem. and Ind.*, London, No. 47 (1969) p. 1703.

Continuous Pyrolysis of Plastic Wastes

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Relationship of Plastic Waste Disposal to Overall Waste Disposal Problem

According to a recent Battelle Institute report entitled "Role of Plastics in Solid Wastes," the total amount of plastic waste disposed in refuse in 1966 was about 3.8 billion pounds. By 1976, it was estimated that total solid refuse generated in the U.S. will amount to about 450 billion pounds per year. Total plastic wastes are expected to be about 9.5 billion pounds per year with plastic packaging refuse accounting for 70% of the total or 6.6 billion pounds per year.

In order to keep this problem in proper focus, it should be recognized that plastic waste is expected to represent only about 2-3% of the total solid waste problem anticipated for 1976. Furthermore, these figures do not include such things as scrapped automobiles, which are a major source of scrap steel.

Table 1 shows the 1966 estimate of total plastics in municipal refuse broken down by type. It is observed that 38% of the plastics are polyethylene, 21% are polystyrene and 31% are polyvinyl chloride. These three plastic types account for 90% of the total plastic waste.

Table 2 shows U.S. plastics production for 1969. These more recent figures also show that polyethylene, polystyrene and polyvinyl chloride are the big three in terms of utilization, with polypropylene coming up fast. Although phenolics equal polypropylene in production volume, they are not as heavily used in packaging applications as is polypropylene and do not present as much of a disposal problem.

TABLE 1*

Plastic	*MM lbs.*	*% of Total*
Nylon	7.9	0.2
Phenolics	22.5	0.6
Polyacetals	3.5	0.1
Polycarbonate	3.4	0.1
Polyethylene (PE)	1446	37.6
Polypropylene	71	1.8
Polyvinyl Chloride (PVC)	1204	31.2
Polyesters	51	1.3
Polystyrenes (PS)	823	21.3
Urea & Melamine	79	2.0
Urethane Foam	89	2.3
Cellulosics	60	1.5
	3860	100.0

*Taken from report entitled "Role of Plastics in Solid Waste" by M. E. Fulmer, & R. F. Testin, Battelle Mem. Institute, approximately 1967.

Recovery and Recycle of Organic Wastes

It is a well established fact that all organic matter on earth is derived from two sources: (1) Photosynthetic processes in plants which occurred

TABLE 2
U.S. Plastics Production 1969

(Billion Pounds)	'69	*% of '69 Total*
Polyethylene	5.470	29.6%
Vinyls	3.609	19.6
Styrene	3.304	17.9
Polypropylene	1.135	6.1
Phenolics	1.127	6.1
Urea, melamine	0.790	4.3
Polyesters	0.665	3.6
Alkyds	0.642	3.5
Coumarone-indene	0.337	1.8
Cellulosics	0.193	1.0
Epoxy	0.170	0.9
Others	1.034	5.6
TOTAL	18.476	100.0

Source: The Society of the Plastics Industry.

millions of years ago, leaving behind deposits of natural gas, crude oil, and coal, and (2) photosynthesis which is occurring today in aquatic and land plants. Recent efforts to focus attention on the recovery and recycling of organic wastes rather than their destruction by burning is based on the rather belated recognition that these organic wastes are part of a very valuable storehouse of organic building blocks which should be kept in the form of reduced organic carbon and recycled in organic systems rather than oxidized to CO_2 and water.

On a weight basis, almost all plastics, synthetic textiles, synthetic detergents, and many modern paints are derived from photosynthetic processes which took place during the paleozoic age. The synthetic organic products derived from petrochemicals are, for the most part, resistant to biodegradation by bacteria, and fungi are not useful as foodstuff for man or beast. As a result of the slowness with which these synthetic organic products biodegrade, they tend to accumulate faster than they are reassimilated.

Union Carbide has underway various research and development projects which may help to solve some of the disposal problems created by the use of synthetic organic products. Carbide was one of the first to produce and sell a soft or biodegradable synthetic detergent in this country. In cooperation with the Dept. of the Interior we are studying the anaerobic treatment of synthetic organic wastes. As a long range research project, we are exploring the possibility of synthesizing plastics which will be both biodegradable and useful in packaging applications. At the present time, none of the large volume packaging plastics sold today is biodegradable. The subject which this paper will discuss in some detail is concerned with a process which we believe may be useful in converting waste plastics into useful organic substances as an alternative to burning them. This process may also convert plastics into products which are more readily biodegradable.

Continuous Pyrolysis of Plastic Waste

Background

During the last 15 years, Union Carbide has developed a considerable amount of technology pertaining to the continuous pyrolysis of plastics in order to convert high molecular weight polymers into low molecular weight polymers. This process differs from the process called destructive distillation in that no carrier gas is used, the process is more nearly isothermal, and only small amounts of gases and carbon are formed as byproducts.

By suitable control of product through-put rate, temperature, and temperature gradient, it is possible to convert, on a continuous basis, plastic material into a wax, a grease, or a liquid, depending on which is desired. The material can also be converted into a gas for use as a fuel or a raw material. These pyrolysis products have been found to be useful in certain applications which will be discussed later. They possess chemical reactivity which permits them to be further converted into a variety of derivatized products which are also useful.

We wish to describe this technology because it may be useful in the future as a means of converting waste plastics into useful products, as an alternative to burning them. Also it is possible that many waste disposal engineers are not familiar with the progress that has been made in the plastics industry in the continuous isothermal pyrolysis of plastics.

There are two possible sources of waste plastics suitable for use in this type of pyrolysis process. Waste or scrap plastics generated by plastics producers and fabricators constitute a source of plastics relatively uncontaminated by food, glass, metal containers, and paper products.

The other source of waste plastics suitable for this process is dependent on the outcome of current studies relating to the collection and classification of solid wastes into categories such as metals, glass, plastics, paper, food, etc. Many of the papers at this symposium are concerned with this solid waste segregation concept.

Description of Pyrolysis Process

Figure 1 is a photograph of a small, laboratory size continuous pyrolysis unit. It consists of an electrically heated 1 1/4" diameter thermoplastics extruder connected to an electrically heated pyrolysis tube which is, in turn, connected to a

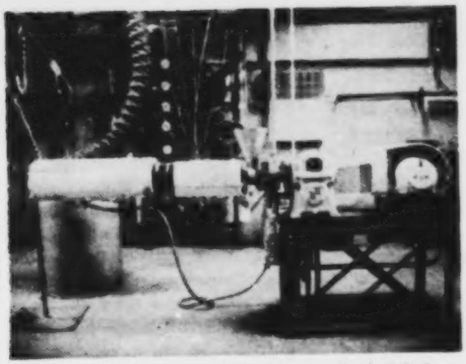

Figure 1: Laboratory Size Continuous Pyrolysis Unit

heat exchanger to cool the pyrolyzed product below its ignition temperature in air. Figure 2 shows a block diagram of such an apparatus.

Figure 3 shows a diagram of an extruder showing its components. The purpose of the extruder is to compress, melt, and pump the molten polymer into the pyrolysis section of the apparatus. Equipment of this type is necessary because of the extremely high melt viscosity and poor heat transfer characteristics of plastics. Because of the design of the screw and the high torque applied to it by the gear box, it is possible to melt the plastic, raise its temperature to 300°C, and place it under sufficient hydraulic pressure so that it can enter the pyrolysis tube.

Figure 4 shows a simplified diagram of a pyrolysis tube. It is of annular construction so as to

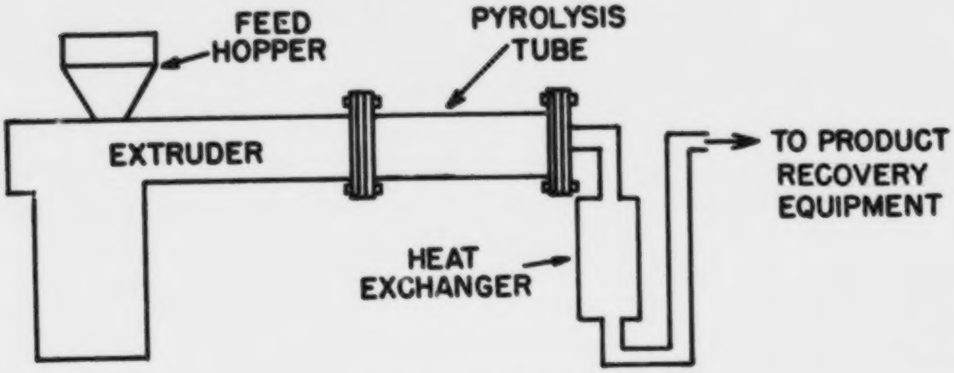
FEED HOPPER
PYROLYSIS TUBE
EXTRUDER
TO PRODUCT RECOVERY EQUIPMENT
HEAT EXCHANGER

Figure 2: Continuous Pyrolysis Unit

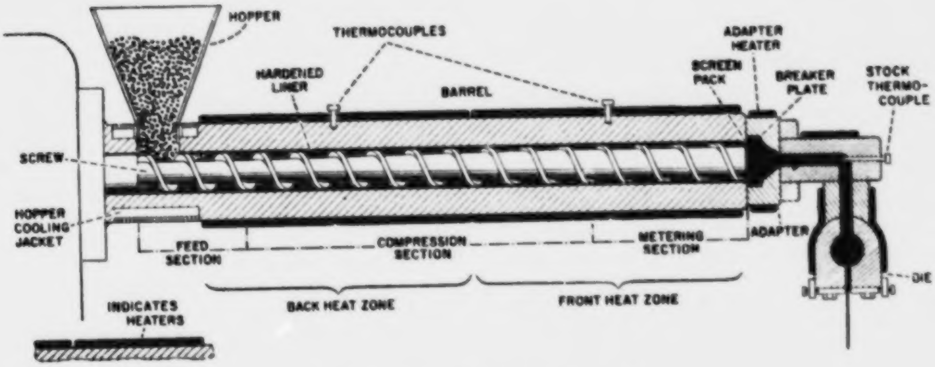
HOPPER
THERMOCOUPLES
ADAPTER HEATER
SCREEN PACK
BREAKER PLATE
STOCK THERMO-COUPLE
HARDENED LINER
BARREL
SCREW
HOPPER COOLING JACKET
FEED SECTION
COMPRESSION SECTION
METERING SECTION
ADAPTER
DIE
BACK HEAT ZONE
FRONT HEAT ZONE
INDICATES HEATERS

Figure 3. Cross Section of a Typical Extruder

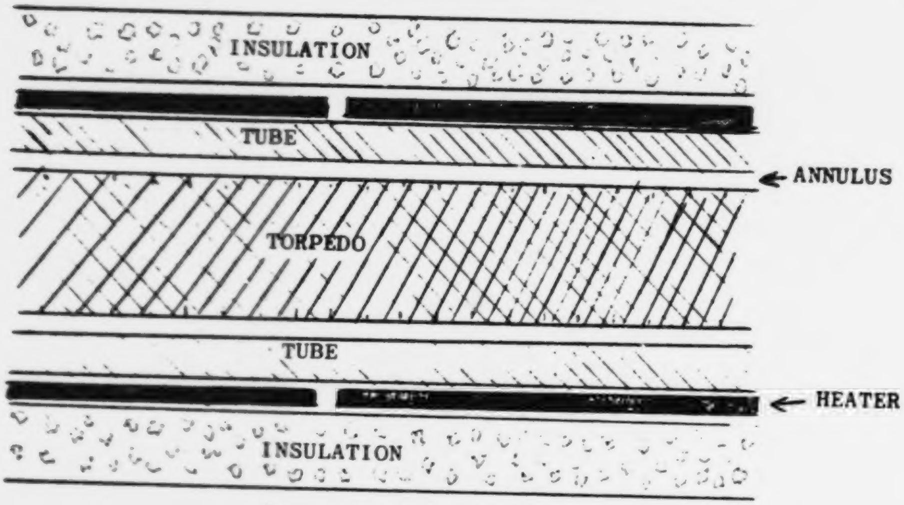

Figure 4: Longitudinal Section of Pyrolysis Tube

heat the molten plastic up to pyrolysis temperatures uniformly and rapidly. The extent of pyrolysis is determined by the temperature and residence time of the polymer in the pyrolysis zone. Because of the fact that all of the plastic goes through the same time-temperature cycle, the resulting product is quite uniform in molecular weight compared to the products obtained by non-isothermal pyrolysis processes such as destructive distillation.

Figure 5 shows a photograph of a 100 pound per hour pyrolysis unit. The heat exchange is not shown. Mounted next to the tube is a device which measures the viscosity of the pyrolyzed product continuously and controls the pyrolysis temperature automatically so that the same viscosity product is made at all times. Such an automatic feed-back controller is a very important feature of a process which will have to accept a non-uniform feedstock.

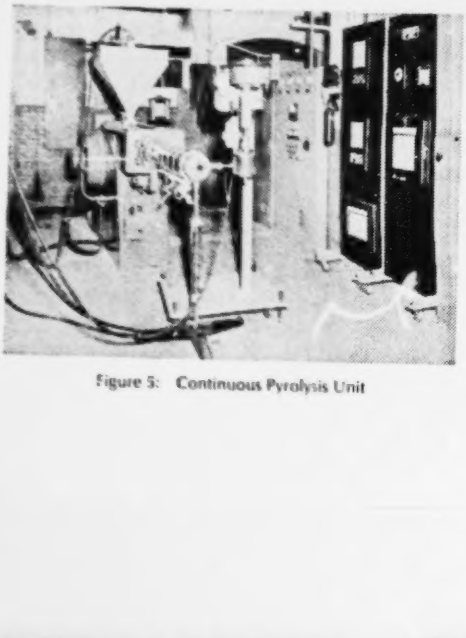

Figure 5: Continuous Pyrolysis Unit

Operating Conditions Used in Pyrolyzing Polyolefins

Using the type equipment described earlier, we have successfully pyrolyzed many thermoplastics. A partial list is given below:

High density polyehylene
Low density polyethylene
Polypropylene
Ethylene — propylene copolymer
Ethylene — ethyl acrylate copolymer
Ethylene — vinyl acetate copolymer
Polystyrene
Styrene — butadiene copolymer
Styrene — acrylonitrile copolymers
Polyvinyl chloride

In addition, we have co-pyrolyzed various combinations of these polymers. This paper will discuss the operating conditions used in the pyrolysis of the first four polymers listed above.

Table 3 shows typical data for the pyrolysis of high density polyethylene using the 1¼" extruder — pyrolyzer described earlier. The plastic fed to the unit had a melt viscosity at 140°C of several million centipoise.

All the products listed in the above table were white waxes, melting around 125°C. They were recovered as flakes using a set of chill rolls.

Table 4 gives operating data for the pyrolysis of DYLT polyethylene. The products were soft

TABLE 3
Conditions for Pyrolysis of High Density Polyethylene

Temperature, Degrees Centigrade					
Extruder		*Pyrolysis*	*Heat*	*Throughput Rate*	*Melt Viscosity 140°C*
Zone 1	*Zone 2*	*Tube*	*Exchanger*	*gms/hour*	*Centipoise*
350°	460°	437°	215°	2700	304,000
350°	460°	457°	205°	2580	32,000
320°	475°	465°	150°	2500	3,000
350°	460°	505°	195°	1800	450

TABLE 4
Conditions for Pyrolysis of Low Density Polyethylene (DYLT)

Temperature, Degrees Centigrade					
Extruder		*Pyrolysis*	*Heat*	*Throughput Rate*	*Melt Viscosity 140°C*
Zone 1	*Zone 2*	*Tube*	*Exchanger*	*gms/hour*	*Centipoise*
	Initial Resin Viscosity				264,000
350	460	410°	190°	2760	30,000
350	460	440°	235°	2760	3,000

white waxes. DYLT (mol. wt. 12,000) is borderline between a wax and a plastic.

Table 5 gives operating conditions for producing greases from DYNH polyethylene. Temperature are 100°C higher for production of greases than for production of waxes. Even in the temperature range 550-625°C, it is possible to make a product which is over 90% grease. Note the effect of decreasing the throughput rate at 600°C on yield and melting point of the final product.

TABLE 5
Conditions for Pyrolysis of DYNH Polyethylene

Pyrolysis Temp°C	*Throughput Rate, gms/hr*	*% Yield*[a]	*Ring + Ball*[b] *M.P. °C*
555°	2058	97	111.5
600°	3216	97.5	107
600°	2670	95.5	104
600°	2124	91.0	60
625°	2496	90.3	68
625°	1944	88.5	58.5

a. Wt. % gross product not distillable at 160°C and 20mm.
b. Applies to product after distillation.

Table 6 gives operating conditions for the pyrolysis of polypropylene. At 500°C and 1800 gms/hour throughput rate, polypropylene gives almost the same viscosity product as does high density polyethylene. The products obtained in each instance are hard waxes. Operation at longer residence times gives lower viscosity products which are soft waxes and greases.

Table 7 shows the relationship between pyrolysis temperature and melt viscosity of pyrolyzed ethylene-propylene rubber gum stock. It is observed that pyrolysis temperatures near 500°C and rates near 2000 gms/hour result in a pyrolyzate having a melt viscosity about the same as that of polyethylene and polypropylene.

TABLE 6
Pyrolysis of Polypropylene

Temperature, Degrees Centigrade					
Extruder		*Pyrolysis*	*Heat*	*Throughput Rate*	*Melt Viscosity 170°C*
Zone 1	*Zone 2*	*Tube*	*Exchanger*	*gms/hour*	*Centipoise*
350	400	450	195	1500	4200
350	400	450	215	1800	1700
350	400	500	215	1860	520
350	400	525	230	1800	210

TABLE 7
Pyrolysis of Ethylene-Propylene Rubber Gumstock

Temperature, Degrees Centigrade				*Throughput Rate gms/hour*	*Melt Viscosity 140°C Centipoise*
Extruder Zone 1	*Zone 2*	*Pyrolysis Tube*	*Heat Exchanger*		
400	400	450	187	2340	312,000
300	340	420	165	1800	32,000
300	410	450	300	1920	3,000
370	400	497	300	1980	300
370	400	515	300	1980	65

In order to pyrolyze polyvinyl chloride, it is necessary to either neutralize the HCl which is evolved by dehydrohalogenation or remove it by using a vented extruder. Dehydrohalogenation of PVC has long been known to be a chain reaction which can be controlled by adding small amounts of tin compounds as stabilizers. If PVC is heated excessively, as in pyrolysis, the stabilizer is quickly depleted by the evolved HCl. Addition of sodium or calcium carbonate to react with the evolved HCl is one way to handle this problem. Because HCl evolution takes place at temperatures below that at which most polymers undergo pyrolysis, it is possible to remove evolved HCl by the use of a vented extruder which operates under a vacuum. This allows the evolved HCl to be recovered and sold for credit.

Changes in Unsaturation with Extent of Pyrolysis

As shown by the data in Table 7, the most noticeable structural change which accompanies chain scission is an increase in carbon-carbon double bonds. In the case of high density polyethylene, which is essentially linear, pyrolysis increases the internal trans unsaturation and the vinyl unsaturation. The vinyl unsaturation results from disproportionation which occurs between two chain radicals formed by random chain scission. The trans unsaturation results from thermal isomerization of vinyl double bonds.

Vinylidene double bonds $\text{-C-} \parallel \text{CH}_2$ are not formed by the pyrolysis of linear polyethylene. All of the other polymers shown in Table 8 are branched and yield vinylidene as well as vinyl and trans double bonds when pyrolyzed. Vinylidene double bonds arise as a result of disproportionation between chain radicals formed by random chain scission of branched polymers.

After pyrolysis has proceeded to such an extent that an average of several chain scissions per original molecule have occurred, it is observed that the pyrolyzed product contains on the average one double bond per molecule. These double bonds are useful in two ways: they make the product more susceptible to biodegradation, and they are useful as reactive sites for further chemical modification.

TABLE 8
Changes in Unsaturation with Extent of Pyrolysis

Product	*Melt Viscosity CPS*	*Trans*	*% C=C As Vinyl*	*Vinylidene*
High Density Polyethylene	300,000	0.086	.253	-
	31,000	0.091	.307	-
	2,900	0.177	.508	-
Low Density Polyethylene DYLT	264,000	0.017	0.05	0.132
	30,000	0.046	0.116	0.228
	3,000	0.101	0.259	0.314
Ethylene Propylene Gumstock	150,000	0.714	0.084	0.440
	28,000	0.824	0.148	0.671
	5,000	0.832	0.303	0.913
	1,420	0.886	0.396	1.[illegible]1
	380	0.719	0.481	1.27
Polypropylene	520	2.41	0.553	0.711
	210	2.72	0.642	1.07

Pyrolysis of Plastic Wastes

Up to now we have discussed the pyrolysis of individual plastic types. Before discussing the pyrolysis of plastic wastes, it is advisable to better define the term. By plastic waste we mean plastics which are unsuitable for recycle and reuse in the form of plastics. There is a popular misconception that discarded plastics can somehow be "cleaned up" and made reusable for the plastics industry. The fallacy of this notion lies in the fact that very rigid quality control with regard to purity and uniformity are required of plastics which are fabricated in the industry's high speed fabrication devices. Because of economic considerations, it is already customary to recycle clean scrap and trim. Industrial plastic waste is seldom suitable for refabrication because of contamination. At the present time, we can recognize two distinctly different types of plastic wastes which may require somewhat different types of pyrolysis equipment.

Single or Two Component Systems

The best example of this is high density polyethylene, which is fabricated into pipe, blown bottles, trash containers, trays, etc. This material is seldom made into film. Sources of this plastic suitable for pyrolysis will be manufacturers and fabricators. Another large source of this plastic should result from current efforts to learn to separate municipal wastes. High density polyethylene can also be copyrolyzed with other polymers with which it is compatible, such as polypropylene. The pyrolysis technology described earlier applies to such single and binary blends.

Multicomponent Plastic Wastes

Multicomponent plastic waste represents the largest potential source of waste plastics suitable for pyrolysis. For this discussion, it is assumed that the technology of separation of this plastic waste from metal, glass, and wood products has been achieved, but that further separation into plastic types is impractical.

Because of the anticipated presence in this mixture of plastics which split out volatile components such as HCl, acetic acid, and plasticizers, this pyrolysis equipment should contain a vented section to draw off these volatiles. The resulting plastic mixture, which is largely a mixture of polymeric hydrocarbons, can be pyrolyzed to any extent desired.

Although the available data pertaining to the pyrolysis of multicomponent plastic wastes as described here is limited, we see no reason why this technology cannot be developed if it is needed. By the use of modern methods of process control, it is possible to automatically control process variables so as to make a product of constant melt viscosity. As shown in the previous tables, hydrocarbon polymers do not vary markedly with respect to the pyrolysis conditions required to reach a given lower viscosity.

Application for Pyrolyzed Polymers

No specific application work has been done on the pyrolysis products of waste plastics. The applications which will be discussed are offered to illustrate the point that uses for certain pyrolyzed plastics have been found. Speculation based on our experience will be offered as to what applications might be developed for the pyrolysis products of waste plastics.

Hard Waxes from High Density Polyethylene

When high density polyethylene is pyrolyzed to a melt viscosity of around 500 centipoise (140°C), the resulting product is a hard wax melting around 125°C. This wax is superior in many respects to carnauba wax and has been incorporated into many applications where hard waxes are required such as paste polishes, printing inks, release agents for molding rubber tires, and as a lubricant for high polymers.

This wax can be chemically modified so that it is emulsifiable by reaction of its terminal double bonds with phosphites, maleic anhydride, or thioglycollic acid. Carbide has several patents covering this technology. The principal ones are U.S.P. 3,144,348, 3,409,448, 3,432,343, and 3,422,983. These wax adducts make very fine particle size emulsions, and are useful as self polishing floor waxes, textile finishing agents, and adhesives. Similar products have been described based on polypropylene waxes.

Soft Waxes, Greases, and Adhesives From Low Density Polyethylene

The pyrolysis of low density polyethylene yields waxes and greases which have been made emulsifiable by chemical adduction with polar groups. The wax emulsions have also been used in polish formulations, as textile softening agents, and adhesives. The emulsifiable grease adducts are useful as adhesives. One of the more intriguing applications for such an emulsion is as a sticking agent for making insecticides stay on the leaves of plants. The use of such products reduces the number of applications of pesticide per season which reduces soil and water pollution, insures continuous protection of the plant, and lowers the farmer's cost. This type product is covered by U.S. Patent 3,281,319 issued to Carbide.

Applications for Pyrolysis Products of Multicomponent Plastic Wastes

As discussed earlier, 90% of such wastes consists of a mixture of polyethylene, polystyrene, and polyvinyl chloride. If the extruder unit includes a vented section to remove hydrochloric acid from the dehydrochlorination of PVC and other volatiles such as plasticizers, the polymeric mixture entering the pyrolysis tube will be largely hydrocarbon in nature. Because of the formation of conjugated unsaturation mainly from PVC dehydrohalogenation, the pyrolysis products of this mixture should have the appearance of tar or crude oil, depending on the severity of pyrolysis. In chemical composition the product will be somewhat like petroleum with certain outstanding differences.

A comparison of petroleum crude and such a waste plastic pyrolyzate is shown below:

	Crude Petroleum	*Plastic Pyrolyzate*
Saturated Hydrocarbon	Yes	Yes
Straight Chain	Yes	Yes
Branched Chain	Yes	Yes
Cyclic	Yes	Possibly Traces
Unsaturated Hydrocarbons	Yes	Yes
Straight Chain	Traces	High
Branched Chain	No	Yes
Aromatic	Yes	Yes
Alkylbenzene	Yes	Styrene Toluene
Styrene Telomers	No	Yes
Naphthalenes	Yes	No
Phenanthrenes	Yes	No
Sulfur Compounds	Yes	No

The most noteworthy aspect of this comparison is the absence of polynuclear aromatic hydrocarbons in the plastic pyrolyzate compared with the petroleum crude. Another important difference is the fact that the pyrolyzate "tar" can be made to have a higher molecular weight than petroleum.

This plastic pyrolyzate should be useful in upgrading asphalt compositions for heavy duty service. In the form of aqueous emulsions or in the melted form, it can be used as an agricultural mulch, where it should be superior to asphalt because of the absence of carcinogens such as polynuclear aromatic hydrocarbons.

Because of its similarity to petroleum, it is obvious that pyrolyzed plastic waste could serve as as petrochemical raw material source in future years, either for fuel or for chemical synthesis. It also appears likely that this low molecular weight product can be used as a carbon source for the synthesis of proteins by microorganisms.

CONCLUSION

We have described a process for the continuous pyrolysis of plastics which utilized equipment developed by the plastics industry for the rapid and efficient extrusion of molten, high viscosity plastics, connected to an annular pyrolysis tube. Operating conditions for the continuous pyrolysis of certain plastics into specific products are described and applications for such products discussed.

This approach may also be useful in the reclamation of multicomponent plastic wastes for use as raw materials for the petrochemical industry, as a carbon source for the synthesis of proteins by microorganisms, and as a fuel.

Destructive Distillation of Used Tires

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and
J. R. LAMAN
Firestone Tire and Rubber Company

The disposal of used tires of all types is becoming an ever increasing national problem. The industry is increasing production of passenger, truck, and bus tires at a rate of 7 percent a year. Approximately 215 million units were shipped in 1968. The rubber industry consumed 5.5 billion pounds of rubber, 400 million pounds of fabric, and over 2.5 billion pounds of carbon black in 1968.

Most of this material eventually shows up on scrap piles in the form of worn-out tires. Figure 1 shows a typical pile of scrap tires which can be found in many locations around the country. Until recently, no use for most of these tires was recognized. A small proportion are retreaded or reclaimed. In the past many have been burned haphazardly in open air dumps. Burning generates large quantities of particulates, hydrocarbons, and sulfur and nitrogen oxides. The problem then becomes one of air pollution rather than solid waste pollution.

Some tires have been disposed of in landfill operations, but they make poor landfill. Their bulk density is quite low, and they do not readily degrade.

Minimal quantities are consumed in such miscellaneous uses as bumpers on boat docks and for prevention of soil erosion. Basically industry, retail dealers, and municipalities are faced with a problem which is not easily solved by conventional solid waste disposal techniques. In general the problem is most critical in areas of high population density.

Table 1 shows rubber consumption in tires over the past five years and projected consumption through 1975. Although the tonnage consumption of reclaimed rubber in tires will remain relatively constant, the percentage of reclaim is constantly declining. Thus a larger percentage of all new rubber articles produced will become solid waste. It is clear that over one million long tons of scrap tires over and above those that are reclaimed or recapped will be produced annually. It should be noted that additional large quantities of non-tire rubber goods are also scrapped annually.

The Firestone Tire and Rubber Company has been cognizant of this problem. We have approached the problem from the standpoint of finding uses for this huge quantity of hydrocarbon-rich waste. The most logical approach seemed to be to recover the hydrocarbons by use of a pyrolytic technique.

After an initial period of bench scale experimentation, during which time we were able to conclusively demonstrate the feasibility of the approach, we sought a location where we could conduct pilot scale tests. We were interested in

Figure 1: Pile of Scrap Tires

TABLE 1
Rubber Consumed in Tires and Tire Products in U.S.A.
(Thousands of Long Tons Annually)

Year	*New Rubber*	*Reclaim*	*Total*	*Reclaim as % of Total*
1965	1306	162	1468	11.0
1966	1412	160	1572	10.2
1967	1326	137	1463	9.4
1968	1606	150	1756	8.5
1969 (Prelim.)	1722	143	1865	7.7
1970 (Est.)	1830	146	1976	7.4
1971 "	1915	147	2062	7.1
1972 "	2006	150	2156	7.0
1973 "	2079	152	2231	6.8
1974 "	2173	154	2327	6.6
1975 "	2271	159	2430	6.5

Total U.S.A. rubber consumption in 1969 was 2,589 thousand long tons.

obtaining sufficient quantities of the products for analyses and evaluations.

At the U.S. Bureau of Mines Coal Research Center in Pittsburgh, Pennsylvania, we located the equipment shown schematically in Figure 2. This unit, known generally in the coal industry as the Bureau of Mines — American Gas Association (BM-AGA) Pilot Plant, is usually used for studying the coking properties of coals.

We entered into a cooperative research program (wholly funded by the Firestone Tire and Rubber Co.) to study destructive distillation (carbonization) of scrap tires in a batch type pilot plant operation. The results of this work are further detailed in the following tables.

The apparatus consisted essentially of a hermetically sealed retort which was heated to the carbonization temperature in an electric furnace. Volatile effluent was passed from the retort into a series of condensers which separated the heavy oils into crude fractions. The lighter components then passed through an electrostatic precipitator to remove entrained particulate matter. Following the precipitator were acid and caustic scrubbers for removal of basic and acidic components from the volatile hydrocarbons and gases. The gases were then dried, and light oils were removed by condensation in a dry ice-acetone trap. The noncondensible gases were passed through a metering system and then to a gas holding tank where a portion of the gas was retained for analysis. The remaining gas was flared.

The light oil scrubbing system shown in the table was not used in this study. We were able to obtain excellent material balances using the equipment without the light oil scrubbers.

Table 2 describes the assorted types of raw materials tested in this study. Shredded whole passenger tires, containing both rubber and fabric, were tested as well as ground rubber containing no fabric. Samples containing bead wire were also evaluated. We also tested samples prepared from truck tires to evaluate the effect of higher percentages of natural rubber found in these materials.

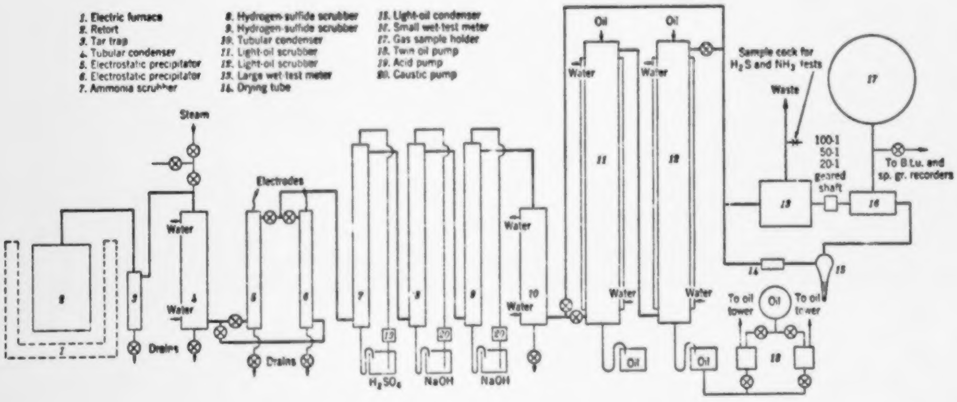
1. Electric furnace
2. Retort
3. Tar trap
4. Tubular condenser
5. Electrostatic precipitator
6. Electrostatic precipitator
7. Ammonia scrubber
8. Hydrogen-sulfide scrubber
9. Hydrogen-sulfide scrubber
10. Tubular condenser
11. Light-oil scrubber
12. Light-oil scrubber
13. Large wet-test meter
14. Drying tube
15. Light-oil condenser
16. Small wet-test meter
17. Gas sample holder
18. Twin oil pump
19. Acid pump
20. Caustic pump
Steam
Water
Water
Drains
Electrodes
Drains
H_2SO_4
NaOH
NaOH
Water
Water
Oil
Oil
Water
Water
Water
Water
Oil
Oil
Sample cock for H_2S and NH_3 tests
Waste
100-1
50-1
20-1
geared shaft
To B.t.u. and sp. gr. recorders
To oil tower
Oil
To oil tower

Figure 2: Schematic of BM-AGA Pilot Plant

TABLE 2
Description of Raw Materials Tested

Test No.	*Source*	*Description*
PT-1	Whole Passenger Tires	Shredded, Beads Removed
PT-3	" " "	" " "
PT-4	" " "	Shredded, Beads Added
PT-2	Passenger Tire Tread	35 Mesh (No Fabric or Beads)
PT-5	Whole Passenger Tires	3-Inch Pieces, No Beads
PT-6	" " "	Quartered
TT-3	Whole Truck Tires	Shredded, Beads Removed

The yields of solid, liquid, and gaseous products from carbonization of scrap tires under a variety of conditions are shown in Table 3. Each test was conducted on approximately 100 lbs. of raw material. A typical test required 7 to 14 hours to completely devolatilize the charge.

TABLE 3
Yields of Carbonization Products

		Yields, Weight Percent				
Test	*Temp., °C*	*Residue*	*Heavy Oil*	*Light Oil*	*Gas*	*Total*
PT-1	500	42.0	45.2	4.2	5.0	96.7
PT-3	900	52.3	14.0	6.5	20.8	97.3
PT-4	500-564	41.8	41.3	4.3	5.5	97.4
PT-2	500	44.8	45.6	1.7	3.2	95.6
PT-5	500	40.3	44.6	3.3	4.8	98.0
PT-6	500-900	42.1	42.7	5.5	7.2	100.0
TT-3	500	36.5	48.7	4.3	5.0	95.7

Tests PT-1 and PT-3 give a direct comparison of the effect of carbonization temperature on the product distribution. At the lower temperature on the product distribution. At the lower temperature (500°C), less residue and gas is produced with nearly 50 percent of the charge being converted to oils. At 900°C a substantially larger portion of the charge is converted to solid residue and gas with much less oil being produced.

Test PT-4 indicates that the inclusion of beads in the charge had little effect on the outcome. The wire was stripped clean of all organic material during carbonization and was easily separated from the solid residue.

Test PT-2 shows that the product distribution is changed very little by using fabric-free rubber. The low yield of light oil in this test was due to incomplete devolatilization of the residue.

Tests PT-5 and PT-6 were conducted using much larger pieces of whole tires. In Test PT-5, three-inch squares of passenger tire were carbonized. In test PT-6, quartered passenger tires were carbonized. The only noticeable effect from these larger pieces was a substantial increase in the rate of carbonization. This can probably be attributed to better heat transfer in the larger pieces.

When shredded truck tires were carbonized, a significant decrease in the yield of solid residue was noted. The yield of heavy oil increased a corresponding amount. Although the exact reason is not known, the higher natural rubber content in truck tires appears to produce more volatile products when subjected to pyrolytic conditions.

Table 4 presents some of the properties of the solid residues produced when scrap tires are carbonized. No significant relationship between either the carbonizing temperature or the type of raw material and the properties of the solid residue produced was apparent. The sulfur contents of the residues were approximately double the sulfur contents of the vulcanizates carbonized. This indicates that most of the sulfur is nonvolatile and remains in the residue during carbonization.

TABLE 4
Properties of the Solid Residue

Test	*Temp. °C*	*Percent Fixed Carbon*	*Percent Ash*	*Percent Sulfur*	*Heating Value, BTU/lb.*
PT-1	500	86.3	9.6	2.0	13,470
PT-3	900	90.5	8.3	1.7	13,500
PT-4	500-564	87.7	9.2	1.9	13,490
PT-2	500	74.8	10.2	2.3	13,720
PT-5	500	83.1	12.7	2.0	13,020
PT-6	500-900	85.4	13.6	2.5	12,640
TT-3	500	80.1	16.5	3.2	12,250

Table 5 presents some of the data obtained from analysis of the heavy oils by the coal tar method. Two points are of special interest in these data. Of most significance is the very high aromatic content of the oil produced at 900°C relative to that produced at 500°C. Secondly, the truck tire rubber produced significantly more olefins and less paraffins and naphthenes than the passenger tire rubber. The presence or absence of fabric in the rubber had little effect on the nature of the oils.

The properties of the gaseous products we more markedly influenced by carbonization temperature than were the properties of the other products. These data are presented in Table 6. In general, the heating values of the gases produced at higher temperatures were lower because of higher percentages of hydrogen and low molecular weight hydrocarbons. The truck tire rubber produced a gas with a relatively high content of C_3 to C_5 hydrocarbons, and thus it had a very high heat content.

The properties of all of the volatile products were analyzed by gas chromatography. Space limitations do not allow presentation of these

TABLE 5
Analyses of Heavy Oils

Test	Temp., °C	Percent* Residue	Neutral Oil, Volume Percent Olefins	Aromatics	Paraffins and Naphthenes
PT-1	500	39.6	15.5	51.5	33.0
PT-3	900	30.1	13.0	84.8	2.2
PT-4	500-564	35.5	17.5	51.6	30.9
PT-2	500	39.8	16.0	54.2	29.8
PT-5	500	30.4	19.0	50.6	30.4
PT-6	500-900	35.2	12.0	56.8	31.2
TT-3	500	27.6	25.0	51.4	23.6

*Distilling above 350°C at atmospheric pressure.

TABLE 6
Gas Properties

Test	Temp., °C	Specific Gravity	BTU per cu. ft.	Percent Hydrogen
PT-1	500	0.628	922	54.97
PT-3	900	.460	765	54.29
PT-4	500-564	.658	835	47.83
PT-2	500	.599	890	49.80
PT-5	500	.739	921	54.52
PT-6	500-900	.479	762	58.93
TT-3	500	.781	1,145	49.48

data here. The oils, both heavy and light, were shown to be extremely complex mixtures. In excess of fifty components were identified in the various oil fractions. In addition, many additional unidentified components were separated.

CONCLUSIONS

We have clearly demonstrated the technical feasibility of destructive distillation of scrap tires on a large scale. The products thus produced can be expected to find application in a number of areas. Roughly 45% of the products are solid carbonaceous residues. It is conceivable that these materials could be used in applications such as filter char, as particulates in concrete or asphalt, or as smokeless fuels. The liquid and gaseous products can be used as fuels. Although they are extremely complex mixtures, and as such are not an economical source of a particular hydrocarbon, it is conceivable that a class of compounds for a particular application could be separated economically.

There are two major questions concerning pyrolytic conversions of scrap tires which remain unanswered. The first is the suitability of this type of waste for continuous processing rather than batch processing. The second is whether product applications can be found which will make this method of waste disposal (of scrap rubber) economically attractive. We at Firestone believe that both of these questions can be answered affirmatively and feel that we are well on the road to a solution to one of the nation's major waste disposal problems.

ACKNOWLEDGMENTS

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A more detailed account of this work has been published as Report of Investigations No. 7302, Bureau of Mines, U.S. Dept. of the Interior, "Destructive Distillation of Scrap Tires," by D. E. Wolfson, *et al.*, 1969.

Economic Evaluation of a Commercial Size Refuse Pyrolysis Plant

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INTRODUCTION

Cities Service Oil Company's initial interest in refuse pyrolysis (destructive distillation of wastes in the absence of air) was based on the potential of the process as a source of crude oil. As a company that refines more crude oil than it produces, it is constantly seeking and evaluating the economics of alternative sources of crude oil.

Municipal waste (composed of 80% carbonaceous materials) is accumulating at a rate of 480 thousand tons per day, and appears to offer a significant and long-term feedstock for synthetic crude production through pyrolysis, providing the technological problems be resolved and the processing costs be comparable to that of conventional crude oil.[1,2,3]

As a result of the growing population and increasing affluence, the U. S. is faced with a municipal solid waste disposal problem of such magnitude that an effective solution presents a formidable challenge to our technological capability.[4] That the problem is a serious one is beyond dispute. Among the factors contributing to this situation are:

- The production of refuse is increasing at a faster rate than the growth in population, as clearly shown in Figure 1. Present daily per capita refuse production approximates 4.5 lb. This is equivalent to a U. S. total of 172 million tons per year.[5,6]
- There exists a decrease in available sites for landfill disposal, particularly in areas adjacent to large metropolitan centers.
- The increasing use of plastics and other synthetic materials presents problems for existing disposal methods.

Imaginative attempts are being made to cope with this mounting burden of solid waste. A recreation ski slope is currently being built out of trash near Chicago;[7] a Japanese firm has developed a compacting machine to produce construction blocks from crushed garbage which are then sheathed in steel or asphalt prior to use;[8] a Pittsburgh firm plans to shred, demoisturize, and subsequently extrude the refuse into combustible-fuel blocks, etc. However, none of these appears to offer a suitable method of disposal for the staggering amount of refuse being generated.

Unquestionably there is a need for an alternative method of refuse disposal that neither utilizes large areas of valuable land nor contributes to air or water pollution.

Pyrolysis offers the potential for such a solution. In addition, pyrolysis provides a means for reintroducing into the energy cycle what is now lost to waste. The diagram as shown below depicts the role pyrolysis will play:

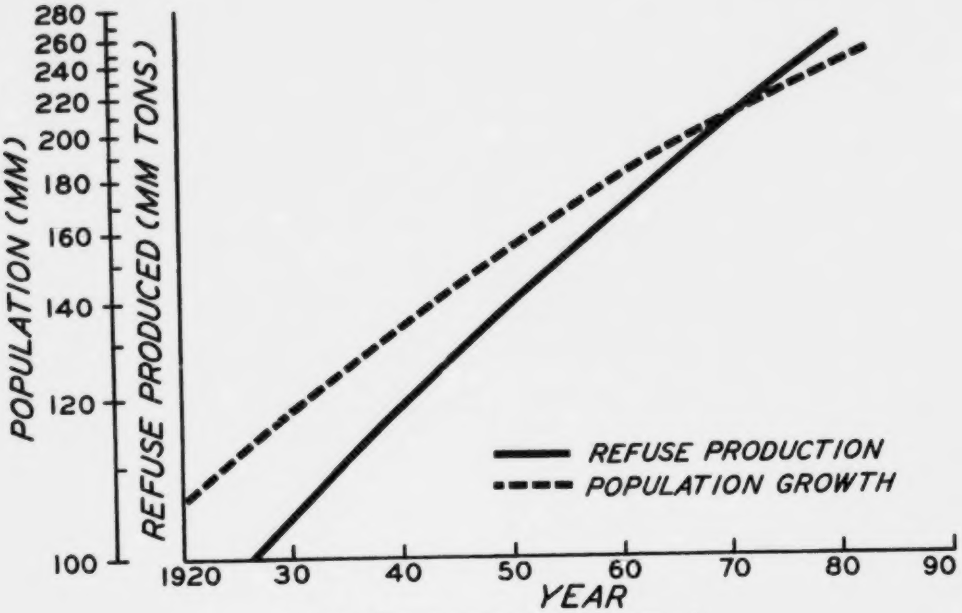
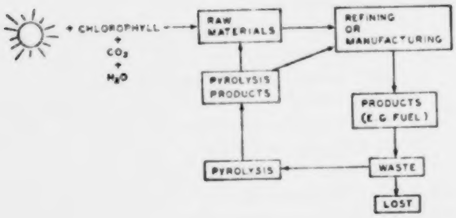


Figure 1: Refuse Production vs. U.S. Population Growth



General Approach

In order to elucidate the parameters involved in the pyrolysis process and provide the inputs needed for a detailed economic evaluation, a bench-scale project was initiated. Outside sources possessing the necessary equipment and having conducted prior research in this area were employed, in order to obtain the necessary laboratory data expeditiously.[9]

Following a one-year laboratory study,[10] a detailed evaluation was undertaken to determine the economics of a commercial size plant.

Experimental

A schematic of the apparatus used to conduct the refuse pyrolysis experiments is shown in Figure 2. The equipment consisted of a stainless steel retort and train of cold-traps capable of operation under reduced pressures. The composition of the laboratory refuse mixture (see Table 1) was based on reported values with the exclusion of inorganic material to facilitate handling. For each run, the

TABLE 1
Municipal Refuse Components
(Wt. %)

Component	*Picked, Dried*	*As-Is*
Miscellaneous paper	29	25
Newspaper	17	14
Plastic, leather, rubber	12	4
Garbage (food waste)	8	12
Grass, tree leaves	17	10
Corrugated box board	8	7
Wood	5	7
Textiles	4	3
Glass, ceramics, stones	-	10
Metals	-	8
	100	100

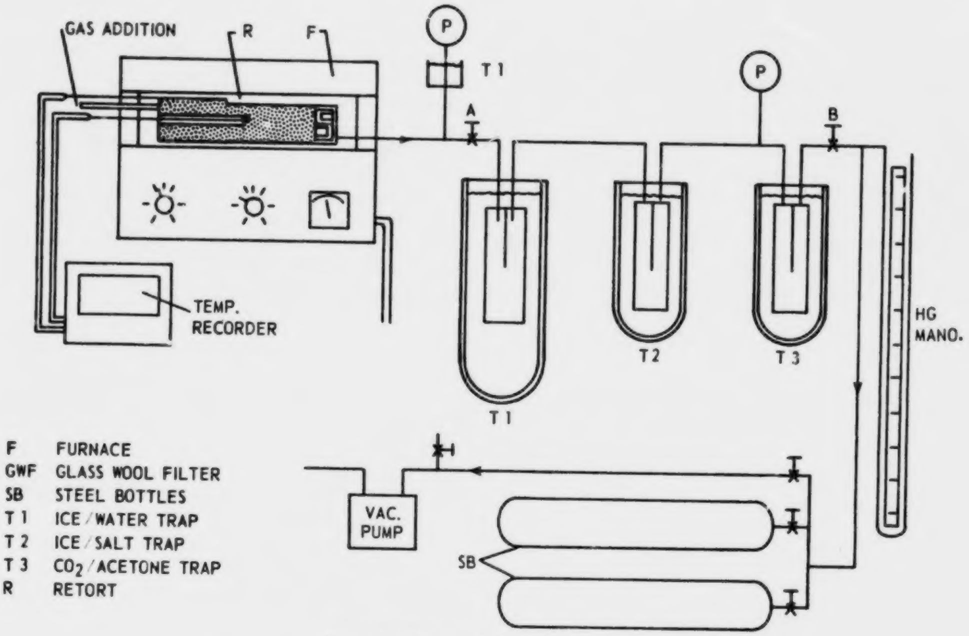


Figure 2: Diagram of Pyrolysis Apparatus

retort was charged with 100 grams of the previously prepared (shredded and dried) refuse mixture. The retort was then placed in a furnace preheated to 500°F. The temperatures of both the charge at its center and the furnace were subsequently monitored by a recording potentiometer. The heating rate was calculated as the average time required to raise the temperature of the charge from 212°F to 1700°F.

Pyrolysis of the refuse mix gave rise to four basic products: gases, water, organic liquids, and char. The product distribution as shown in Figure 3 was found to vary with changes in the heating rate. At slow heating rates of 5-20°F/min., the char make-up was due to longer retention time in the retort. Faster rates of 40-70°F/min., gave higher liquid yields due to faster removal of the distillates and less coking. In addition, the gaseous fraction increased due to further cracking.

Gas product distribution as a function of heating rate is given in Figure 4. However, composition of the gas produced was observed to change considerably as the run progressed (Figure 5). Based on the nature of the gas distribution, it would appear possible to segregate a fuel-rich or hydrogen-rich stream. More likely, the total gas produced would be used as fuel to sustain the pyrolysis process during operation. Since these gases are free of sulfur, chlorine and particulate matter, their burning will not contribute to air pollution.

The organic liquid portion, representing the potential source of synthetic crude, was of primary interest. The liquids were separated into three fractions, water-soluble volatiles, water-soluble, and water-insoluble non-volatiles. The water-soluble volatile portion, while representing about 10% of the organic make, does contain valuable petro-chemicals. Product distribution as a function of heating rate for this portion is shown in Figure 6. The water-insoluble non-volatiles, a black, tarry material, formed an average 85% of the organic liquid fraction. It consists mainly of oxygenated compounds: esters and acids.[11]

The other major product is a high-ash char having a heat value of slightly more than 10,000 BTU/lb. A flow sheet of the pyrolysis process including detailed product identification and yield is provided in Figure 7.

Economic Evaluation

Commercial Conceptualization

The commercial size refuse pyrolysis plant consists of the following unit sections: feed storage

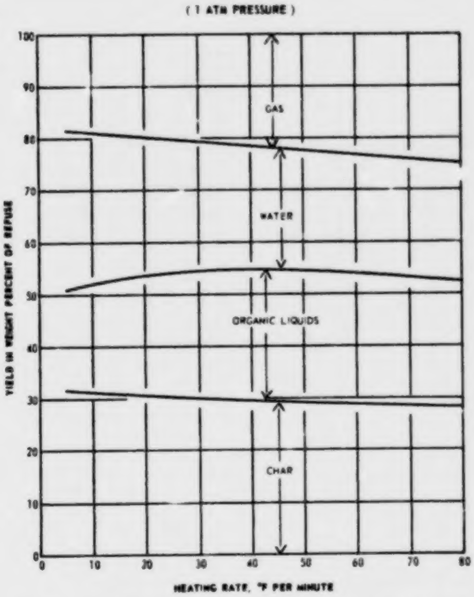


Figure 3: Yields From Pyrolysis of Municipal Refuse Organic Matter vs. Heating Rate

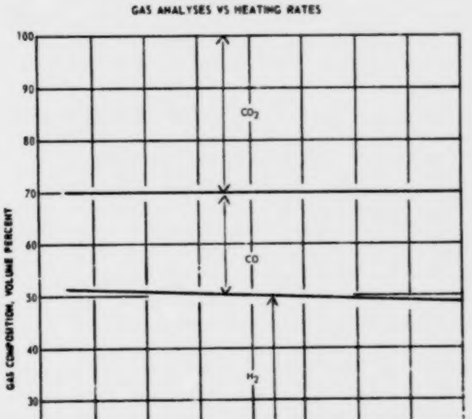


Figure 4: Gas Analyses vs. Heating Rates

and preparation, pyrolysis, product separation, and storage.

Figure 8 is a flow sheet containing the functional parameters of such an operation. Plant considerations range from the underground storage capability through initial salvage operation, feed preparation to the pyrolysis chamber itself. After volume reduction by 50% in the rotary kiln, the products are separated into gases, liquids, and char, which are then upgraded to salable products. The gas may be sold or utilized as fuel in the operation of the system.

Bases for Capital Investment

Using the general framework and operating mechanism of a commercial plant, the investment considerations for such a unit naturally follow. Two general approaches are conventional for capital investment estimates of a commercial unit:

- Scale-up from pilot plant operation
- Comparison of capital investments for similar process operations.

Cities Service did not pursue the process through the pilot plant stage; therefore, the estimates of capital investment costs are based on analogous processes.

Pyrolysis is a well-known technique used to produce coke from heavy petroleum oils (coking), or coke from coal (carbonization), or charcoal from wood (distillation). Coking is widely used in the U. S., with over 2 MM b/d of heavy oils being converted to coke and lighter petroleum oils. Carbonization of coal is used all over the world to produce coke for the blast furnace, together with relatively smaller amounts of by-product chemicals. Distillation of wood has fallen out of practice, primarily due to the high cost of the raw material and the decreasing values and use for the charcoal.

A review of pyrolysis techniques indicates that such systems have been developed to operate over a wide range of conditions, including those presumed necessary for solid waste pyrolysis. For example, both fluid bed and non-fluid bed systems collect a solid product using the gas and/or liquid products to provide the necessary heat. However, other systems have been designed to maximize the yield of the liquid or gaseous fractions.

Thus, there is a wealth of analogous technology applicable to the pyrolysis of solid materials including operating and economic data. It remains to (1) select the process best suited for solid waste pyrolysis (modifying as necessary), (2) further delineate the economics of such a

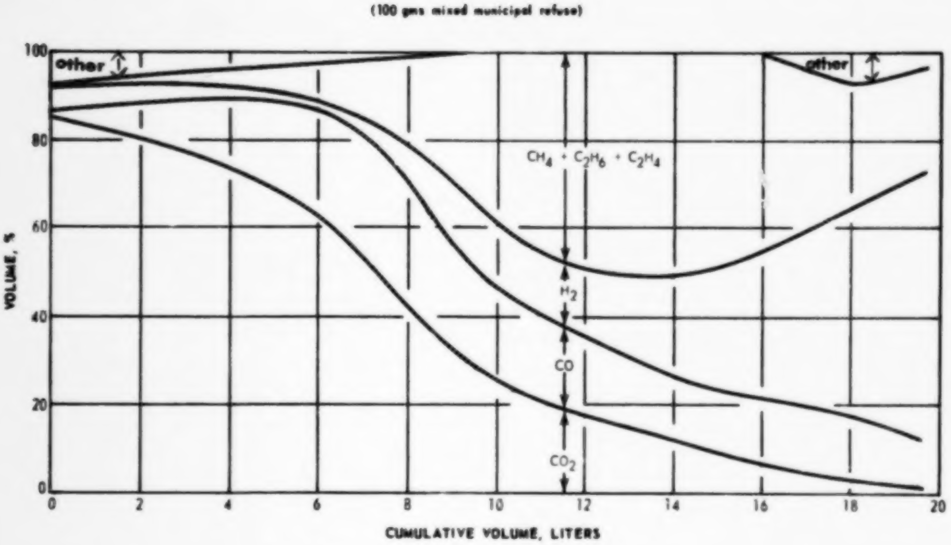


Figure 5: Typical Product Distribution of Pyrolysis Gases

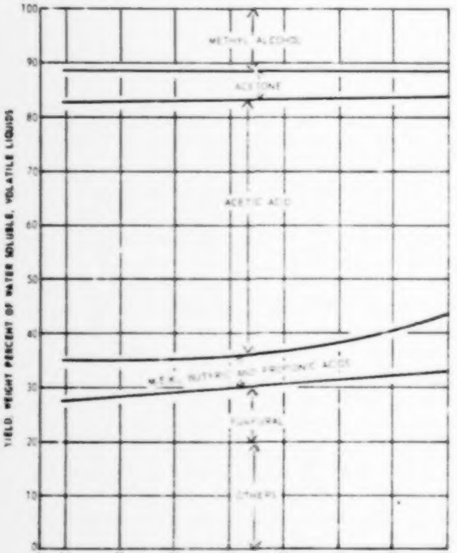


Figure 6. Proportions by Weight of Water-Soluble, Volatile Organic Liquids vs. Heating Rate

process, and (3) demonstrate its use on solid waste in a pilot or demonstration plant.

The following were selected as the bases for the refuse pyrolysis plant investment estimation:

FMC Coal Carbonization

This estimate was prepared for the Office of Coal Research by FMC in 1965 for a commercial coal carbonization plant feeding 3.5 MM tons/year of coal (10,000 tons/stream day).[14] The coal (Illinois No. 6) contained 4% moisture and 6% ash. A detailed estimate was made based on pilot plant results charging about 100 lb./day of coal. The carbonizer section is complex, containing four separate zones to carbonize the coal at progressively increasing temperatures.

Table 2 summarizes the FMC estimate corrected to refuse feed capacities of 5,000 tons/calendar day (5,533 t/sd) and inflated to present (1969) cost levels by the Nelson Index. The following corrections were applied: Nelson inflation index 1969/1965 = 1.23; no correction for feed quality; scale power correction of 0.7. The 0.7 scale power correction was utilized instead of the more customary 0.6 factor, because many of the economic parameters are of a speculative nature. The corresponding estimated cost of such a plant is $6.19 MM.

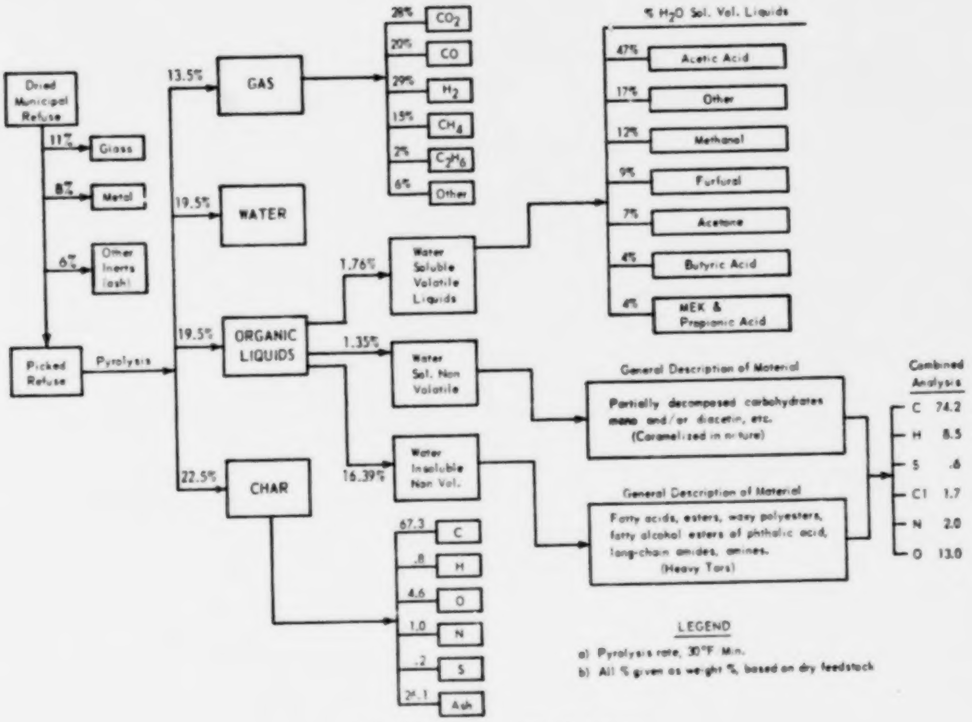

Dried Municipal Refuse
11%
Glass
8%
Metal
6%
Other Inerts (ash)
Picked Refuse
Pyrolysis
13.5%
GAS
19.5%
WATER
19.5%
ORGANIC LIQUIDS
22.5%
CHAR
28%
CO2
20%
CO
29%
H2
15%
CH4
2%
C2H6
6%
Other
1.76%
Water Soluble Volatile Liquids
1.35%
Water Sol. Non Volatile
16.39%
Water Insoluble Non Vol.
% H2O Sol. Vol. Liquids
47%
Acetic Acid
17%
Other
12%
Methanol
9%
Furfural
7%
Acetone
4%
Butyric Acid
4%
MEK & Propionic Acid
General Description of Material
Partially decomposed carbohydrates mono and/or diacetin, etc. (Caramelized in nature)
General Description of Material
Fatty acids, esters, waxy polyesters, fatty alcohol esters of phthalic acid, long-chain amides, amines. (Heavy Tars)
Combined Analysis
C 74.2
H 8.5
S .6
Cl 1.7
N 2.0
O 13.0
67.3
C
.8
H
4.6
O
1.0
N
.2
S
26.1
Ash
LEGEND
a) Pyrolysis rate, 30°F Min.
b) All % given as weight %, based on dry feedstock

Figure 7: Schematic of Pyrolysis Process

The bases for the FMC Coal Carbonization process adopted to pyrolysis use includes: capital cost without contingency and working capital; coal storage for 8 1/2 hours (3,600 tons); venturi oil scrubber for gas washing; general facilities (no product storage); utilities purchased (steam plant included); no sulfur recovery.

United Engineers Low Temperature Carbonization

In 1954, United Engineers estimated a low temperature (900°F - 1,250°F) coal carbonization process to produce fuel gas, coke, and chemicals.[13] The latter includes separate streams of light oil, acid oil, creosote oil, pitch, and liquor. The estimate is quite detailed, although it is old and suffers from a large uncertainty due to use of an inflation index.

The plant was based on a feed of 8,520 t/sd of a bituminous coal containing 15% water and 15% ash. Although the carbonizer is a single vessel, simple fluid bed reactor heated by recycle gas, the system has a pre-oxidizer wherein the coal is heated and its caking properties eliminated. Table 3 illustrates the United Engineers estimate. The second column revises the estimate to a 1969 cost basis. The third column illustrates the cost of a similar plant, eliminating a large part of the product separation facilities and the final column corrects these costs to the hypothetical 5,000 t/d refuse pyrolysis plant.

The calculated costs are in excellent agreement with those of FMC, considering that the United Engineers estimate includes a 10% contingency and contains facilities of an unspecified cost for treating water, and even more when the uncertainties in inflation indices and scale-cost relationships are considered. The corrections employed for conversion are as follows: Nelson inflation index 1969/1954 = 1.75; no correction for feed quality; scale power correction of 0.7. The bases for calculation include the consideration of capital cost with 10% contingency without working capital; coal storage of unspecified capacity; oil scrubber for gas washing; no char storage; utilities except for electricity; sulfur recovery.

Hoffman-Fitz Estimate

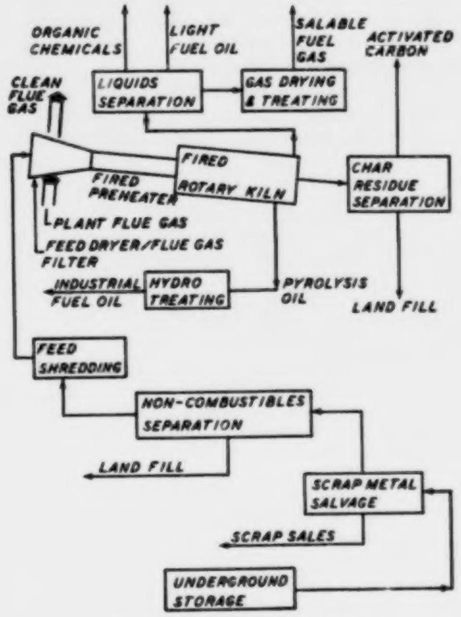

ORGANIC CHEMICALS
LIGHT FUEL OIL
SALABLE FUEL GAS
ACTIVATED CARBON
CLEAN FLUE GAS
LIQUIDS SEPARATION
GAS DRYING & TREATING
FIRED
FIRED PREHEATER
ROTARY KILN
CHAR RESIDUE SEPARATION
PLANT FLUE GAS
FEED DRYER/FLUE GAS FILTER
INDUSTRIAL FUEL OIL
HYDRO TREATING
PYROLYSIS OIL
LAND FILL
FEED SHREDDING
NON-COMBUSTIBLES SEPARATION
LAND FILL
SCRAP METAL SALVAGE
SCRAP SALES
UNDERGROUND STORAGE

Figure 8: Refuse Pyrolysis Plant

TABLE 2
Capital Costs
FMC Coal Carbonization
($MM)

Plant Section	10,000 T/D FMC Estimate	 FMC 1969	Corrected for Refuse 5,000 T/D
Feed Preparation	1.51	1.86	1.00
Carbonization	5.45	6.70	3.60
Oil Recovery	1.41	1.74	.93
General Facilities	1.00	1.23	.66
Total Estimate	9.37MM	11.53MM	6.19MM

The City of San Diego estimated the investment requirements of a refuse pyrolysis plant consisting of eight 50 t/sd plants at approximately $5 M/t/sd or about $2 MM for the total system.[14] Some savings had been taken for replication of the individual 50 t/sd units, but no further details were available. Based on a cost of $250 M per 50 t/sd unit, application of the 0.7 power scale correction factor results in a capital estimate of $6.7 MM for a 5,000 t/d plant. This figure is surprisingly close to the previous estimates, perhaps fortuitously.

Delayed Coking.

A 3,000 b/sd (525 t/sd) coker at 1965 costs requires an expenditure of about $3 MM for battery limits.[14] This investment figure would be increased to about $4 MM to place it on the current basis and provide for the inclusion of some offsite facilities. Using the 0.7 power scale correction factor, an estimate of $21.4 MM is obtained for a 5,000 t/d unit.

This estimate is nearly three times that previously obtained. Part of the difference is certainly due to the elaborate decoking equipment required in the delayed coking process. However, it should be remembered that delayed coking has proven to be more economic than fluid coking, although the latter does not have such decoking equipment and can produce superior yields. It should also be noted that in the case of refuse pyrolysis (or coal carbonization), handling equipment will in general be more expensive than corresponding equipment for delayed coker units operating at about 900°F. Thus the delayed coking estimate must be taken seriously, certainly as seriously as the other estimates for processes which have yet to reach commercialization.

An estimate for the coking of coal tar pitch, as installed in a Japanese plant, has been set at $4 MM for a 250 metric t/d yield plant.[15] If the coke

TABLE 3
Capital Costs
United Engineers Coal Carbonization
(8,520 T/SD, $MM)

Plant Section	U.E. Estimate 1954	U.E. Estimate 1969	U.E. Estimate Corrected	Corrected for Refuse 5,000 T/D
Feed Prep & Carbonization	4.26	7.43	7.43	5.13
Distillation	4.45	7.78	(1.50)	1.04
Product Treating	.30	.52		
Sulfur Recovery	1.10	1.92		
Steam Generation	.37	.65	.65	.45
Liquid Product Storage	.20	.35		
Buildings and General	.83	1.45	1.45	1.00
Total Estimate	11.51MM	20.10MM	11.03MM	7.62MM

product is obtained at the conversion rate of one-half feed, this estimate is in reasonable agreement with those cited previously for delayed coking. The Japanese plant uses a single distillation tower to separate an unstated amount of liquid products. The process scheme is similar to delayed coking with hydraulic decoking achieved over a 48-hour cycle.

Internal Estimate

Based on an internal estimate for a 73,000 t/d shale oil plant, a capital investment of $30 MM was estimated for a 15,000 t/d refuse pyrolysis plant. This investment did not include inventory storage or flue gas cleaning and is essentially inside battery limits.

Incineration

The Rust Engineering Company provided an estimate of $5 MM for 500 t/d incinerator installation.[16] The unit included refuse feed storage and handling equipment. The $5 MM figure was corrected to $4.5 MM to place it on a current basis comparable with other estimates. Assuming an incinerator of 5,000 t/d capacity could be built, the corresponding capital investment is estimated to be $24.4 MM.

Pyrolysis units should be less expensive than incineration systems due to the following:

- Pyrolysis units are operated at somewhat lower temperatures, thus are cheaper to build and less critical to operate.
- Pyrolysis units can be built to large capacities (corresponding to the 5,000 t/d - 10,000 t/d capacities presently utilized in petroleum coking and coal carbonization), whereas incineration units, because of critical operating difficulties, seem presently limited to 1,000 t/d units. Therefore, large pyrolysis units should afford 'economy of scale.'
- Pyrolysis units do not require the large air blower/compressors needed in incineration.
- Pyrolysis units possess greater thermal efficiency, and do not require high pressure fluid bed systems to obtain their increased efficiency.
- Pyrolysis units (which per se do not vent any products to the atmosphere) require essentially no air pollution control equipment.

It should also be noted that pyrolysis is ecologically less regressive than incineration with respect to ultimate conservation of resources. Pyrolysis converts waste organic matter to potentially useful products rather than to carbon dioxide. Even if the products of pyrolysis prove ultimately useful only as fuel (which is extremely unlikely), such sulfur-free fuel would be burned in highly efficient power stations as exist in electric power installations, rather than in highly inefficient incineration units.

Capital Investment

Table 4 reviews the inside battery limit capital investment estimates of five different operations, delineating working ranges from which to base the commercial pyrolysis ISBL investment.

TABLE 4
Bases for Estimate*
(5,000T/D)

Source	$MM	
From FMC fluid bed coal estimate	6.19	
From United Engineers estimate (1954)	7.62	
Hoffman-Fitz estimate	6.7	
From delayed coking	21.4	
Incineration	24.4	
Best		16MM

*Summary of investments (ISBL) for refuse pyrolysis plant excluding product appreciation and feed preparation.

There are wide discrepancies between the different operations which cannot at this time be rationalized. However fortuitous the agreement between the first three investments, they nonetheless suffer from the usual difficulties in estimating the cost of a plant for which the prototype has yet to be built. In the absence of a process design, then, the ISBL investment of a 5,000 t/d pyrolysis plant is estimated to be $16 MM. The 5,000 t/d plant represents a reasonable commercial size installation considering the logistics of refuse availability and associated materials handling problems.

In this analysis, off-sites must include the usual expenditures for a grass roots site and process plant. In addition, expenditures for feed and product storage, materials handling, and a system for rendering the feed into suitable form for pyrolysis must be considered. The latter is presently unknown. However, it is certain that at least a portion of the refuse requires a reduction in size. It is most reasonable that large objects (automobile parts, bed springs, etc.) can be segregated and fed to crusher-shredders, while household refuse (including bottles and cans) may be fed directly to the pyrolysis unit.

Site preparation and materials handling costs are expected to be unusually high. For example, if the refuse is obtained by truck, with an average truckload of 20 tons, 275 truckloads per day would be received, which, distributed over 24 hours, corresponds to a load every five minutes.

An extensive roadway system would be required for dumping over the extent of the site.

This system would have to be coordinated with the feeder system to the process section of the plant. A quotation from a manufacturer indicates that shredding equipment can be obtained for about $200 per t/d capacity installed. Although expensive, this equipment is reported to be capable of disintegrating most refuse and is widely used. The cost of such equipment for the 5,000 t/d plant would be about $1.1 MM.

Costs for product storage facilities, although significant, would not be comparable in magnitude with those associated with the feed preparation and handling.

Therefore, assuming the preceding parameters, total offsites may be estimated to be 40% of ISBL investment for the 5,000 t/d plant. In the case of the conversion of coal to oil (with 50% of the investment in conventional petroleum processing facilities), a 15% contingency was used. With the uncertainty present in the commercial pyrolysis scheme, a 25% contingency was warranted.

Working capital requirements were assumed to cover the following:

1. Interest over a 2-year construction period at 8%
2. Debits for a first-year of operation at 50% of capacity
3. Full capacity operation after this time (with a 360-day operating factor)

Table 5 summarizes the total investment of $32.6 MM required for the 5,000 t/d commercial size refuse pyrolysis plant.

Operating Costs.

The operating costs for such an installation were divided into fixed and variable conversion costs, as seen in Table 6. Operating labor is taken at 15 men per shift, 7 onsite at $4.50 per hour and 8 offsite at $4.00 per hour. Supervision is taken at 30% of labor. Overhead is equal to the total of labor and supervision costs. Maintenance is taken at 5% of onsites and 3% of offsites. Insurance and property taxes were 1.5% of the BL cost. Total electrical and water requirements are nominally taken as an operating expense of $200 M per year in consideration of the FMC and United Engineers estimates.

It is assumed here that heat requirements correspond to that for heating the feed to 600°F (vaporizing all of the water in the feed) with 66% efficiency. Although the assumption that no more heat will be required is optimistic, it is counter-

TABLE 5
Total Investment Including Working Capital
(5,000T/D)

Investment	*$MM*	
Inside Battery Limits	16.0	
Offsites	6.4	
Total IBL & Offsites		22.4MM
Contingency (25%)	5.6	
Construction interest, 1st year (8% × 33%)	0.7	
Construction interest, 2nd year (8% × 67%)	1.5	
Start up extraordinary (assumed 8% × 100%)	2.4	
Additional costs		10.2MM
Total Investment		32.6MM

TABLE 6
Operating Costs
(5,000T/D)

Fixed	*Cost ($MM)*		
Labor	.49		
Supervision	.15		
Overhead	.64		
Maintenance			
onsite	1.00		
offsite	.24		
Taxes and Insurance	.49		
Total Fixed Conversion Costs		3.01MM	$1.65/T
Variable			
H_2O & Power	.20		
Fuel	.70		
Total Variable Conversion Costs		.90MM	$ .49/T
Total Operating Costs		3.91MM	$2.14/T

balanced by the assumption that no sensible heat will be recovered from the product effluent. This requirement corresponds to about 1.1 MM Btu/t of as-is refuse, or 550 Btu/lb at 35 cents/MM Btu.

Product Values

The useful products from pyrolysis are gases, liquids, and solids. As a minimum consideration, they are considered to have fuel value. As fuel, all of the products have the advantage of being sweet. The gas is, however, of low heating value, unsuitable for home use. The liquid is also of low heating value (and possibly somewhat corrosive due to its carboxylic acid content) but could conceivably be used as a substitute for heavy fuel oil. The solids include char and inorganics. The gas produced may be valued at 35 cents/MM Btu as fuel. A variation of ±5 cents/MM Btu was found to have an insignificant effect on the overall conclusions.

As produced, the organic liquids from refuse pyrolysis are only marginally suitable for use as fuel with an estimated value of 0.5 cents/lb or roughly $1.50/bbl. Chemical analyses of these liquids indicate they contain fair quantities of low molecular weight acids, alcohols and ketones such as acetic acid, methanol and acetone (i.e., aliphatic oxygenates), and some phenolic materials such as phenol and cresol (i.e., aromatic oxygenates).

Separation of the organic pyrolyzate into its component aliphatic and aromatic oxygenates could increase the value to 1 cent/lb as a crude chemical commodity. On this basis, the crude organic liquids would be valued at $2.50/bbl to $3.00/bbl. Further upgrading would depend upon ease of purification.

The char produced from refuse pyrolysis had an analyzed heat value of 10,277 Btu/lb. High-grade bituminous coal is typically 14,000 Btu/lb. The difference is to be found in the fact that the char has a high (26%) ash content. This ash is the residue from the coatings and fillers used in paper as well as the dirt and inorganics that are expected to be present in refuse. Methods such as screening or flotation may be suitable for reduction of this ash content by physical separation.

The char may be activated and provide a product useful for tertiary water treatment at a market value of 3 cents/lb to 5 cents/lb. This would be dependent upon removal of a substantial part of the inorganics, at least the water solubles. With the present high ash content, it is worth fuel value of about $5.60/t.

Metal and ash residues may be reclaimed from the pyrolysis operations, either before or after retorting. The ash and other inorganics may be worth $1/t as sanitary landfill. The iron metal may be worth $15 to $20/t as scrap.

Table 7 summarizes the product value assignments with associated process yield data.

For the purposes of this evaluation, it has been assumed that a municipality would deliver refuse to the pyrolysis installation free of charge along with a monetary payment for disposal. This payment is considered a subsidy and included in the estimation of the total annual receipts for the venture. A subsidy of $2/t to $8/t is not unreasonable when a city such as New York spends $8/t on incineration, excluding collection costs.

TABLE 7
Pyrolysis Product Values
(5,000T/D)

Product	*Value ($)*	*Wt.%*
Gas	0.35/MM Btu	11.5
Liquids	2.50-3.00/bbl	15.0
aliphatic and aromatic oxygenates	1.00-1.50/bbl	
remainder as fuel	1.50/bbl	
Solids		
char (.03/lb to .05/lb)	60-100/ton [1] 5.60/ton [2]	16.5
ash and inorganics	1.00/ton	12.0
scrap metal	15-20/ton	8.00

The remaining portion constitutes water either initially present in the feed or formed during pyrolysis.

[1] activated carbon for tertiary water treatment

[2] fuel only

Profitability

Evaluation of refuse pyrolysis as an investment opportunity was calculated using our (ECO-5) computer program on the IBM 1130.[17] To calculate the Internal Rate of Return or Profitability Index (P.I.), the previously delineated capital investment considerations for the 5,000t/d plant were utilized. Additional considerations used in these calculations are contained in the Appendix.

For the plant, four levels of subsidy payments for two different product value assumptions were considered.

1. Base case where products are considered to have fuel value only, equivalent to $2.80/t of raw refuse.
2. Optimistic case where the products are all considered to have the best available market value.

Table 8 contains a summary of the basic input data for each case at the various subsidy levels with the corresponding P.I.'s that were generated.

At the low subsidy level of $2/t for the base case, a return of 5.5% could be expected. At a subsidy level of $4/t, refuse pyrolysis offers a utility type return of 10.8%. Increasing the level of subsidy payments to $6/t raises the P.I. to 15.4, which is still quite low for such a high risk venture. The dependence of P.I. on the level of subsidy payments is further illustrated in Figure 9. We see here that subsidy payments of more than $9/t must be received in order for the P.I. to reach 20, which would be a minimum level for serious consideration of a high-risk investment such as refuse pyrolysis.

Figure 10 shows the general relationship between P.I. and capital investment for a typical base case at a subsidy level of $2/t. As expected, an increase in capital investment requirements causes a dramatic decline in the projected return for the venture.

The interrelationship between P.I., level of subsidy payments, and capital investment is depicted in Figure 10. We see here the affect on P.I. of changes in capital investment at the various subsidy levels. It is interesting to note that, as the level of subsidy payments is increased, the range of P.I. values corresponding to the various capital requirements is lowered.

In general, the P.I. was found to be more sensitive to variations in the level of subsidy payments than fluctuations in the capital investment requirements. Further, the sensitivity of P.I. to the level of subsidy payments in going from products as fuel only, to the assignment of higher market values, is somewhat dampened.

With respect to the economics presented here, we consider that refuse pyrolysis, while a technically viable process, does not represent an attractive investment opportunity for an industrial organization. Additional factors must also be considered.

An industrial organization, in order to realize an acceptable return on investment, would need to be in receipt of subsidy payments. These payments would be determined as much by local political considerations as economic factors. Therefore for refuse pyrolysis to represent a good investment opportunity, it would have to make it on its own merits as a source of salable commodities rather than being dependent upon subsidy payments.

Furthermore, a performance bond will be required by a municipality to insure uninterrupted refuse disposal. Stringent conditions of this nature recently caused the cancellation of an agreement between San Francisco and a railroad where the railroad was to transport compacted refuse to a distant landfill site.[10] With the much greater risk of operating problems involved in a refuse pyrolysis operation, the threat of major losses due to default on performance could become a significant factor.

In view of the low profitability and potential political entanglements, it is concluded that refuse pyrolysis does not constitute a suitable opportunity for industrial commercialization.

However, the process should be utilized by municipalities as an effective method of solid waste disposal.

All previous economic evaluations were based on industrial commercialization of this process and suggested a utility-type return. In order to fully demonstrate the economic advantage this process affords a municipality, a further evaluation was conducted. The major changes in the economic considerations are shown below:

- *Industrial Operation*
  Overall capital charges of 30%/year, 10% depreciation, 2% taxes and insurance, and 18% gross return.
- *Municipal Operation*
  Overall capital charges of 12.1%/year, 5% depreciation, 1.5% taxes and insurance, and 5.6% gross return.

The significance of these changes is depicted in the following:

	Industrial Operation ($MM)	*Municipal Operation ($MM)*
Operating expenses (less taxes & insurance)	3.42	3.42
Capital cost	9.77	3.94
Overall costs	13.19	7.36
Cost ($/t)	7.26	4.05

With investment charged off *on a utility basis* (no subsidy included) a municipality could dispose of 5,000t/d of as-is refuse at a cost of $4.05/t. This cost less revenue of $2.80/t for the products as fuel results in a net cost of $1.25/t, substantially below present incineration costs of $8/t to $10/t.

With investment charged off *on an industrial return* (no subsidy included), the cost of refuse disposal becomes $7.26/t. With revenue of $2.80/t for the products as fuel, the net cost of disposal is $4.46/t of as-is refuse. This cost represents the minimum allowance or subsidy an industrial operator must obtain from a municipality to perform the same function.

Refuse pyrolysis unquestionably favors municipal operation on both economic and political grounds. With a minimum of product upgrading, the process offers the municipality a method of refuse disposal with essentially negligible costs.

TABLE 8
Economic Evaluation of Pyrolysis Process
(5,000 T/D Plant, $M)

Annual Receipts	*Base Case*				*Optimistic Case*			
Subsidy Payments								
$2/T	3,650				3,650			
$4/T		7,300				7,300		
$6/T			10,950				10,950	
$8/T				14,600				14,600
Fuel Value Only ($2.80/T)	5,110	5,110	5,110	5,110	-	-	-	-
Gas (Fuel Value)					820	820	820	820
Liquids								
Aliphatic Oxygenates	-	-	-	-	660	660	660	660
Aromatic Oxygenates	-	-	-	-	800	800	800	800
Remainder as Fuel	-	-	-	-	1,560	1,560	1,560	1,560
Solids								
Char (Fuel Only)	-	-	-	-	3,300	3,300	3,300	3,300
Scrap Metal	-	-	-	-	1,370	1,370	1,370	1,370
Ash & Inorganics	-	-	-	-	270	270	270	270
Total Estimated Annual Receipts	8,760	12,410	16,060	19,710	12,430	16,080	19,730	23,380
Total Investment			32,600				32,600	
Profitability Index	5.5	10.8	15.4	18.4	10.8	14.9	18.4	21.4

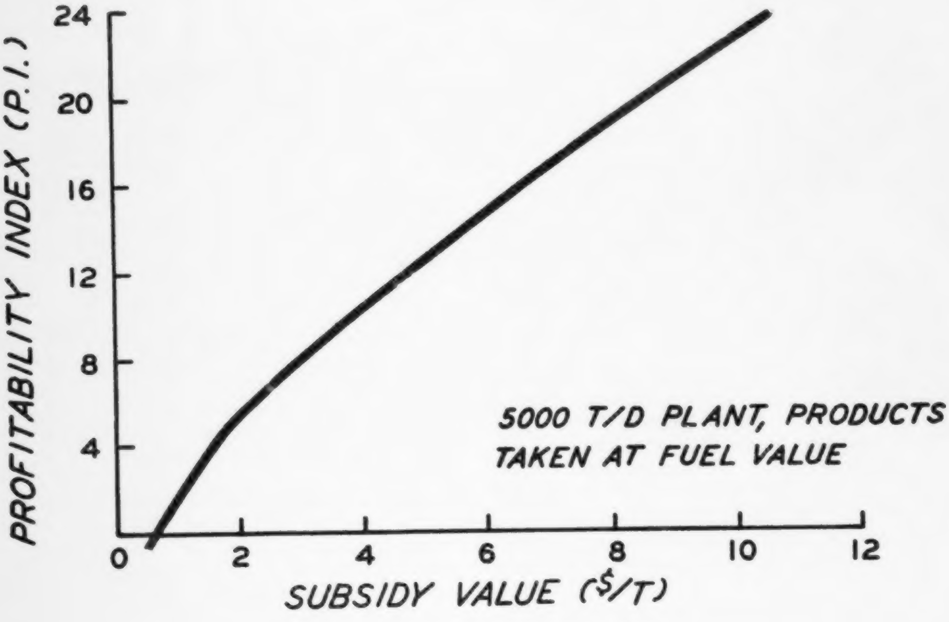


Figure 9: Relationship of P. I. vs. Subsidy Values

CONCLUSION

Pyrolysis is a technically feasible method of municipal refuse disposal having the attendant features of potential production of useful products with no associated environmental pollution.

While a viable process, refuse pyrolysis, represents at best a marginal venture opportunity for an industrial firm. The expected return is deemed

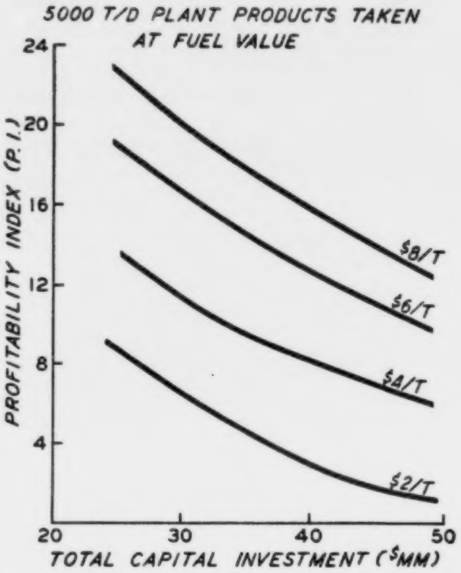


Figure 10: Relationship of P. I. vs. Capital Investment at Various Subsidy Values

insufficient for the risk involved. Further consideration of political and public pressures as well as performance bond requirements add to the risk side while having no offset. Such conditions present a situation offering at best a small return if successful and potentially large losses if unsuccessful.

However, this process would appear to offer an attractive possibility to a municipality, because they do not have to meet private return on investment criteria. Economic analyses indicate (when products are taken at fuel value) that at zero expected return (i.e. non-profit) refuse disposal costs are negligible. In addition it is likely that some partial upgrading of the products could be achieved thereby affording a potential profit.

ACKNOWLEDGMENT

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REFERENCES

1. "Jersey Must Find Some New Ways to Get Rid of Its Garbage," *The Trenton Evening Times*, 7 Oct. 1968.

2. "Waste Disposal-Precious Garbage," *Industrial Research, Vol. 10*, No. 3, March 1968, p. 25.

3. Hoffman, Donald A. and Richard A. Fitz. "Batch Retort of Solid Municipal Wastes," *Environmental Science and Technology, Vol. 2*, No. 11, November 1968, p. 1023-1026.

4. United States Department of the Interior, Bureau of Mines. *Composition and Characteristics of Municipal Incinerator Residues*, Report of Investigations 7204, PB 182673, December 1968.

5. "The Garbage Glut," *Wall Street Journal, Eastern edition*, 16 Feb. 1968.

6. Kovaly, Kenneth A. "What Can You Do with an Avalanche of Garbage?" *Science Digest, Vol.* 66, No. 1, July 1969, p. 70-73.

7. "Garbage: Rosy New Future as Raw Material," *Chemical Engineering, Vol. 75*, No. 9, 22 April 1968, p. 82-84.

8. Hershaft, Alex. "Solid Waste Treatment," *Science and Technology*, No. 90, June 1969, p. 34-42.

9. Friedman, S. B. and E. R. Kaiser. "The Pyrolysis of Refuse Components," (paper presented at the Sixth Annual Meeting of the American Institute of Chemical Engineers, the Symposium on Air Pollution Control through Applied Combustion Science, New York, N.Y. Nov. 26-30, 1967).

10. Kaiser, Elmer R., Arrigo A. Carotti, Russel Smith, Daniel Kasner, and Joseph B. McCaffery. "Pyrolysis of Municipal Refuse," (report to Cities Service Oil Company, August 1, 1968-July 31, 1969).

11. Duggan, Marjorie. "Analysis of Municipal Refuse Pyrolyzates," Cities Service Oil Company private communication, ADI-69-1.

12. United States Department of the Interior Office of Coal Research, *Char Oil Energy Development*, PB 169562, December 1965.

13. Minet, R. G., H. B. Smith, and C. A. Trilling. "Economics of Carbonization by the Low Temperature Process," *Chemical Engineering Progress, Vol. 50*, No. 7, July 1954, p. 342-347.

14. Schuman, Seymour C. "Disposal of Refuse by Pyrolysis," (private communication to Cities Service Oil Company, August 15, 1969).

15. Remirez, Raul. "Novel Process Makes Coke from Coal Tar Pitch," *Chemical Engineering, Vol. 76*, No. 4, February 24, 1969, p. 74-76.

16. Rust Engineering Company, Pittsburgh, Pa., private communication.

17. Carabelli, Paulette, and Robert Zmitrovis. "Synthetic Fuel from Refuse," Cities Service Oil Company internal report, September 1969.

18. Midwest Research Institute. *A State-of-the-Art Survey of Solid Waste Disposal Techniques* (private report to Cities Service Oil Company, May 14, 1969).

APPENDIX

Additional Economic Investment Pyrolysis Plant Considerations

A. Salvage value: 10% of battery limits
B. Construction: two years with 30% of total investment applied during the first year
C. Working Capital
  1. 50 days accounts receivable
  2. Supplies assumed to be represented by 60 days operating and maintenance payroll plus 30 days maintenance materials (materials = 40% of maintenance costs)
  3. 30-day product inventory
D. Start-up Costs
  1. 3 months operator training
  2. 30 days off-test production loss

E. Sales Build-up
   1. 50% first year, 100% thereafter
F. Taxes and Depreciation
   1. Future U. S. Taxes assumed to be 50% of before-tax profit
   2. Depreciation taken on a double-declining balance basis for the life of the installation (11 years for process equipment and 20 years for non-process)
   3. Book depreciation is carried on a straight-line basis over a period of 20 years for non-process and 15 years for process
G. Annual Receipts
   1. Receipts vary with level of subsidy payments
   2. Receipts vary with assignment of products values

Comprehensive In-Plant Solid Waste Survey

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INTRODUCTION

Industrial plants have always concerned themselves with manufacturing products from raw materials by the most efficient and economical means available. Because of the increased awareness and concern for the quality of our environment, we must now closely examine manufacturing operations with regard to the wastes they produce. Solid waste handling, processing, transfer, and disposal systems need to be examined in light of stricter environmental standards for air, water, and land.

This paper describes methods for gathering the data necessary to plan and evaluate industrial solid waste management systems. The data collected can assist both industry and government agencies in planning, designing, and operating industrial solid waste management systems that may encompass a single plant or a number of plants and municipalities. Additionally, knowledge of the magnitude of the solid waste problem could enable state and local agencies to improve their land use planning and solid waste management systems. The availability of information would allow public and private institutions, equipment manufacturers, collection and disposal operators and others to focus their attention on the needs and problems of solid waste management.

Since industrial solid wastes are variable in type, composition, and quantity, and since solid waste management practices are often antiquated, neglected, and inefficient, comprehensive surveys are necessary and highly desirable.

Information Desired

The basic purpose of an industrial solid waste survey is to collect qualitative and quantitative information regarding all aspects of a plant's solid waste management system. Such a survey will provide information that management can use to improve its present system and plan future actions related to solid waste management.

To make a thorough survey, detailed information should be gathered under the general topics of source, storage, transfer, and treatment disposal (Table 1). The minimum information collected concerning wastes should include the source of each waste, its type, physical and chemical characteristics, and rate of generation. Storage practices can be defined by listing the method of storage used, whether open areas or containers; the type and size of container used, if any; and the location of the storage areas. Transfer, or the movement of wastes from one point to another, can be fully described by a determination of the routes followed, the frequency of pickup, and the personnel and equipment required. Treatment,

TABLE 1
Survey Information

Source	Waste type
	Physical and chemical characteristics
	Generation rate
	Location
Storage	Methods used
	Type, size, and location of areas and/or containers
Transfer	Routes
	Collection frequencies
	Personnel and equipment
Treatment/Disposal	Method used
	Waste accepted
	Location and description
	Personnel and equipment
	Evaluation
Miscellaneous	Costs
	Ownership/leasing/contracting

which is distinguished from disposal, is a process that alters the physical state of waste before final disposal. Examples of treatment are compaction, incineration, and grinding. The information necessary to describe a treatment or disposal operation consists of the following: the method used, the waste accepted, the location and description of the site, the personnel and equipment required, and an evaluation of the operation including the determination of the remaining life of the facility.

In addition to the above information, all costs associated with storage, transfer, treatment, and disposal should be determined. To determine all costs, it may be necessary to investigate ownership of facilities and equipment, as well as leasing and contractual arrangements.

The information gathered can be used to construct a flow diagram or model of the system that details the movement and treatment of wastes from their sources through final disposal. Such a model can be used in conjunction with the cost data and qualitative knowledge of the system obtained during the survey to make an analysis of the efficiency of the system. Some common system inefficiencies noted by the Bureau of Solid Waste Management studies include the following:

1. failure to combine or separate waste streams where such action would be beneficial;
2. improper sizing and location of storage containers;
3. unnecessary handling or transfer of wastes;
4. loss of easily salvageable wastes;
5. failure to use the most economical treatment processes, such as handling bulky wastes where compaction would be more economical; and
6. loss of landfill capacity due to the lack of compaction.

Planning

The first consideration in planning a survey is to decide who will conduct the survey. The survey could be done by in-plant personnel or by some outside organization such as a consulting firm. For an objective survey in terms of criticism and evaluation, we recommend that the survey be carried out by an outside organization.

The survey should be planned and administered through the highest possible managerial level in the plant or the company because it will usually be necessary to obtain the cooperation of several departments within the plant. Authorization from the highest possible level will do much to ensure the cooperation of the departments involved.

Initially, the survey director and his staff should meet with representatives of plant management and various departments such as accounting, engineering, production, and maintenance. Several organizational and planning sessions may be necessary. Topics considered at such meetings might include obtaining access throughout the plant, obtaining maps of the plant, having briefings on the existing solid waste management system, determining the location of waste sources and various equipment and facilities, and obtaining background information such as records on costs, total quantities, waste generation rates, and contractual arrangements.

All outside agencies, firms, and individuals involved with the solid waste operations of the plant should be identified. Each should be contacted to obtain cooperation in the survey. Records of their operations that might supplement those obtained from the plant should be investigated. In addition, permission should be obtained to enter and study any of the extra-plant treatment or disposal facilities.

After the initial meetings and contacts, the survey staff should completely familiarize itself with all plant facilities. This can be done by touring the plant and visiting all of the waste sources and the storage, treatment, and disposal facilities owned or operated by the plant, its contractors, and involved municipal authorities.

The organization of the survey itself is the next and final step in planning. Aspects of organization that should be considered are the dates and duration of the survey, field assignments and schedules, equipment, and data forms. Seasonal variation and plant production should be considered when scheduling the survey. Waste generation figures based on a survey during periods of low or high production may be misleading. Another obvious factor to consider when determining schedules is the hours of plant operation and the shift schedule. Potential observation locations for personnel on field assignments might include the scale house, treatment or disposal facilities, and collection vehicles. Having a survey staff member who may move freely about the plant to observe the entire waste management system is also valuable. The staff should be provided with any equipment necessary to take notes, make measurements, or otherwise document the operations. Documentation can best be accomplished with an orderly data collection form and a camera to photograph actual conditions and waste management practices.

Data

After the survey has been completed, the data should be summarized in the simplest fashion to avoid any misinterpretation. All raw data should be included in the report or attached as an appendix. Its inclusion allows an independent analysis and lends credence to the report.

To define the complete solid waste system, the subsystems defined by type of wastes or components of the total system (such as sources, storage areas, storage containsers, transfer areas, salvage, landfill, etc.) may best be studied separately. One means of classifying subsystems might be by the components of the waste systems. Through this approach, the solid waste system is identified by an inventory of points of waste generation and by subsequently following the methods used in removing the wastes from the plant (Figure 1). (Components might include sources, storage areas, storage containers, transfer areas, salvage and landfill.) A schematic diagram showing waste operations and movement through the total solid waste system will provide an understanding of the interrelations among the components of the system. Each component can then be discussed in turn as the waste movement is described.

Another means of classifying subsystems is by following each type of waste from its source to final disposal (Table 2). The number of subsystems varies with the size, complexity, and waste management practices of the plant.

Regardless of the method used to classify the system, the major categories of data needed to summarize each subsystem include source, transfer, storage, treatment, and disposal. These categories can then be broken down into as much detail as desirable.

Recommendations

The detailed, comprehensive survey, when conducted by qualified personnel thoroughly versed in all phases of plant operations and knowledgeable in solid waste technology, should provide some meaningful conclusions. Recommendations will be commonly concerned with larger storage containers and their locations, waste compaction or size reduction equipment, improved housekeeping, and separation for potential salvage or reuse. Whenever possible, alternatives should be presented for each recommendation. Limiting factors and other considerations should be noted. The Bureau of Solid Waste Management's experience in industrial solid waste surveys has indicated numerous universal problem areas that include the following: (1) environmentally unacceptable disposal operations; (2) multiple handling, storage, and transporting of solid waste; (3) lack of coordination between the plant, state, and local officials, and collection or disposal contractors; and (4) manpower and costs. Such situations should be noted during the study and included in the evaluation of the total solid waste management system.

The analysis should indicate areas needing improvement. The existing system should be presented in light of its efficiency, costs, acceptability, practicability, and impact on the plant, its environs, and the community. Such a study and presentation of the results assists management in making the proper decisions necessary to reduce the depletion of resources and to improve the quality of the environment. Improved in-plant han-

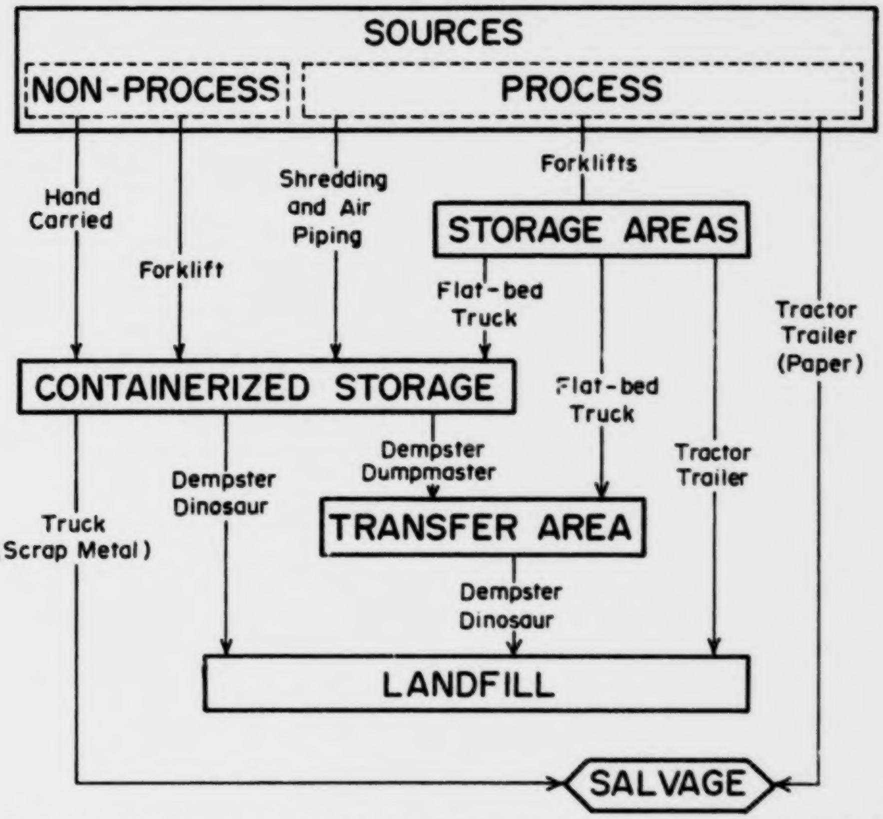
SOURCES
NON-PROCESS
PROCESS
Hand Carried
Forklift
Shredding and Air Piping
Forklifts
STORAGE AREAS
Flat-bed Truck
Tractor Trailer (Paper)
CONTAINERIZED STORAGE
Flat-bed Truck
Dempster Dumpmaster
Dempster Dinosaur
Tractor Trailer
Truck (Scrap Metal)
TRANSFER AREA
Dempster Dinosaur
LANDFILL
SALVAGE

Figure 1: Solid Waste Subsystems Defined by Components (Mention of a Commercial Product Does Not Necessarily Imply Endorsement by the U. S. Public Health Service)

TABLE 2
Solid Waste Subsystems Defined by Waste Classification

General (chemical plant)	*Specific (truck assembling plant)*
General plant wastes	Garbage
	Cardboard
Process wastes	Cloth
	Paper, glass, etc
Ashes	Wood
	Rubber
Scrap	Plastics
	Oils
Construction/demolition wastes	Flammable liquids
	Residues and tars
Miscellaneous burnables	Wastewater treatment sludges
	Cans, bands, wire, etc.
Wastewater solids	Special wastes

dling, storage, and treatment will often produce cost savings that can be applied to improve disposal techniques.

SUMMARY

Industrial solid waste management is very complex and varies from plant to plant depending on size, location, and processes. Like solid waste management in general, it has been neglected for years (and the problems continue to mount). The comprehensive survey can provide a foundation for improving existing problems and practices and the impetus for needed research and new technology.

The survey should be properly designed to gather all data pertinent to an evaluation of a solid waste management system. The sources, type, quantity, storage, transfer, treatment, disposal, and salvage of all the solid wastes should be identified. A clear, concise report summarizing the data and listing conclusions should be the result.

The challenge to the technical and scientific personnel is clear: eliminate or reduce industrial solid wastes at their source and improve present disposal technology. The basis for any improvements is a comprehensive in-plant survey of all types of industrial solid wastes. The survey is a tool to increase management's awareness of the problems and of the need for using present technology or developing new technology.

Solid Waste Management In The Printing And Publishing Industry

RUFUS SHORT
Battelle Memorial Institute

Environmental pollution is not a new problem, but we are only now realizing that man's effect on his environment must be controlled. This conference in Houston is evidence of our determination to bring scientific investigation to bear on achieving environmental balance. Battelle-Columbus is one of many organizations now engaged in systematic research toward this end. In this paper only one aspect of the industrial pollution problem, Solid Waste Management in the Printing and Publishing Industry, is described.

One might ask, why be concerned with the printing and publishing industry? The answer is simply that it is one of the nation's largest industries in terms of the number of manufacturing establishments and the value of product. Furthermore, the industry is widely distributed among all regions of the country; it is found in urban, suburban, and rural locations. Its product is highly visible and is often seen blowing about the countryside. In short, the printing industry, with its 40,000 separate firms, is an important part of every community and must be considered in the broad plan of industrial waste management and control.

This study of the management of solid waste in the printing and publishing industry includes SIC Industry Numbers 2711, 2721, 2731, 2732, 2752, and 2753. These include newspapers, book, and periodical printing and commercial printing, but business forms and package converting are excluded. The term "solid waste" probably requires no definition; here it may be thought of as unused remnants from the printing production process that are not in the form of gas or liquid. The material may be either reused as most scrap paper or metal, or discarded and not recycled. Actually, the vast majority of solid waste from the printing and publishing industry falls into the first category and is either reused in the printing industry or becomes a raw material for other products such as roofing shingles. The term "management" in this context means the direction, control, techniques, and cost of solid-waste collection and disposal.

Since the objective of this study is to acquire information on solid-waste management in the printing and publishing industry, the scope includes the kinds and amounts of solid waste generated, the internal plant collection practices, collection costs, and the methods by which the solid wastes are either recycled or discarded. In addition, any community problems associated with the disposal of this waste must be identified, as must future technical and economic trends that may importantly influence the waste system.

At the present time, most of the data for the study have been gathered, but the analysis has just been started. Consequently, the findings cannot be discussed in any total or final sense, but the research method, the types of wastes generated, and the general pattern of their collection, recycling, or disposal can be described.

The basic research technique used was in-depth interviews with a representative sample of printing-publishing firms from all geographic regions of the country. The in-depth-interview technique places great emphasis on the careful construction of an interview guide and the skill and specialized knowledge of the interviewer. Needless to say, the act of going into a factory and conducting a detailed probe into the rubbish bins and emerging with anything resembling usable information requires some prior planning and knowledge of the production process. It also requires diplomacy. The more than 100 completed interviews have been made by three Battelle economists.

The guide was planned to allow the interviewer to ask a series of questions in the following areas: 1) plant identification and size; 2) primary plant manufacturing activity by SIC code; 3) description of production process, both major and secondary; 4) quality and quantity of solid waste generated at each major production point; 5) techniques and equipment used for collecting solid waste within the plant; 6) methods used for disposing of the waste, including waste that which is recycled and that which is discarded; 7) community problems encountered with waste disposal; 8) costs incurred by the company for waste collection and disposal; and 9) changes anticipated in the individual firm, in the industry, and in the firm's relationships with collectors and dealers that may significantly affect the future management of solid waste.

Approval of this interview guide was received from the Bureau of the Budget early in September, 1969, and the actual field interviewing started soon after.

Concurrently with the construction, verification, and approval of the interview guide, we were determining how to select the interview sample from a population of approximately 40,000 printing and publishing firms.

We originally decided that about 200 interviews would provide the necessary coverage of geographical regions and SIC classifications, but we now believe that the data are probably uniform enough to reduce the sample to about 125. At the present time, we are analyzing the information from the 100 completed interviews to discover the degree of dispersion in the data and the areas where information is lacking. More interviewing will be done if needed.

The sample of interviews was distributed proportionally in each of nine geographical regions in the United States, according to the number of firms in each SIC in each region. The numbers of firms grouped by SIC and geographical region were obtained from the 1963 Census of Manufacturers. Thus, the interviews were distributed proportionally across the country, with interviews for each SIC code within each geographic region but with more interviews in regions of higher manufacturing density.

The names of individual firms in the sample were picked at random from a list of about 6,500 printing and publishing companies having more than 20 employees. With the use of a table of random numbers, 500 names were drawn; this provided the required sample for all SIC's within each geographic region, with some extras. The sample, therefore, consisted of a random group of firms with over 20 employees. The sample did not include enough of the larger firms because these were too few in number to have much chance of being drawn. Also, of course, the sample did not include any firms with less than 20 employees. Consequently, the largest firms in each geographic region were deliberately picked from separate lists and included in the sample, and the interviewer also selected a few small plants at random from the local telephone directory in each of the areas he visited.

When the interviewing trips were actually planned, further structuring of the interview sample was necessary to avoid excessive travel costs. Nevertheless, every effort was made to plan the trips on the basis of the requirements of the sample, and the final group does include small, medium, and large firms in each of the industrial classifications distributed proportionally within each of the nine geographic regions. There is every reason to believe that the information obtained accurately reflects national conditions in the printing and publishing industry.

Because the Project Officer recognized the importance of obtaining the cooperation of industry associations before the interviewing was started, the largest associations were advised of the study and informational meetings were held with the American Newspaper Publishers' Association and the Printing Industries of America. Printing Industries of America has been of great help in publicizing the study and, in some cases, providing an entree to the firms selected in the interview sample. The American Newspaper Publishers' Association has provided very useful data on the amount of waste paper generated by member firms. The cooperation of both of these trade associations has contributed greatly to the success of the study.

Findings

Production Processes and Types of Waste

What have we found out from the 100 completed interviews? Since the analysis of the collected data is incomplete, statements of statistical confidence or projection of waste totals from our sample cannot be made at this time. It is possible, however, to describe the type of waste generated, the production processes by which the waste is generated, and the collection and disposal practices that prevail. First, let us go through the typical printing plant to describe the production processes and the kinds of waste coming from each stage. The work usually flows through a standard series of production stages from art and composition to bindery and finishing.

Clerical and art. The people engaged in these activities generate the usual mixed office waste that consists of paper scraps, a small amount of metal scrap, containers such as paper and plastic coffee cups or soft-drink bottles, and some garbage scraps from food brought to the work place.

Composition or typesetting. The three major types of processes used in this function generate different kinds of scrap. The first process is hot-metal or lead composition such as is commonly found in newspaper plants. The major waste from this process is metal dross, which consists of metal residues and oxides that form on the surface of molten type metal. The second process is typewriter composition, which generates a small amount of scrap paper. With the third system, phototypesetting, scrap film or photosensitive paper if found. Sometimes in larger plants all three processes are employed.

Camera stripping. The principal waste from these departments is exposed film. In addition, there are empty chemical containers and a small amount of mixed office waste of the usual composition. Also, metallic silver from developing solutions is recovered as solid waste.

Platemaking. The process used in platemaking, and therefore the nature of the solid waste, varies according to the printing production system employed. These systems fall into three major categories.

Letter press. Metal in the form of scrap copper, magnesium, and zinc is generated as a result of either spoilage in the production process or discarding used plates. Eventually, all printing plates become metal scrap (plus some plastics) because these plates are all eventually discarded by the printing company. In addition to the metal and plastic scrap, a small amount of waste is incurred from the materials used in mounting the plates, such as blocks of wood or wood composition material.

Offset lithography. Lithographic plates may be either paper, plastic, or metal, and again all of the plates used in the printing process are eventually discarded and become waste. Paper plates may contain silver, which is usually recovered as with exposed film. Metal plates are mostly aluminum; a relatively few are zinc or combinations of metal such as copper and aluminum.

Gravure. Copper gravure printing cylinders are generally cleaned, polished, and reused. Consequently, little identifiable metal waste is generated. However, carbon tissue used in the platemaking process is discarded.

Stereotyping. This is the process used to make the duplicate printing plates commonly used by newspapers employing the letterpress process. Large quantities of scrap "mats," mainly paper but some of plastic, are generated. In addition to these mats, metal scrap in the form of dross is created when stereotypes are remelted.

Press. The largest category of solid waste generated is scrap paper and other substrates resulting from spoilage on the presses. In addition to waste substrates, there are empty ink cans, other chemical containers, rubber cylinder blankets, roller coverings, and wood from sources such as broken and surplus pallets or skids.

Bindery, finishing, and shipping. Scrap-paper trimmings are generated by the finishing operations. In larger operations, some empty containers such as paste buckets become waste. Other types of waste include empty corrugated shipping cartons, used steel strapping, and discarded wood from skids, pallets, and boxes.

In addition to the waste generated by these production operations, there are substantial amounts of waste discarded by people throughout the plant. This waste consists of empty containers of all kinds, used lunch bags, food scraps, metal scraps, a large amount of paper, and whatever people from our affluent society discard as they go through their daily routines. In addition, there may be garbage from a cafeteria.

Amounts

Although the type of waste generated in the printing and publishing industry shows little variation from plant to plant, the amount of waste generated by these establishments fluctuates widely. As might be expected, large establishments spoil more paper than small establishments. The amount of spoilage is also a function of both the printing process and the nature of the end product. Thus, large metropolitan newspapers using the letterpress process spoil about 3 percent of their paper input, whereas smaller newspapers using the offset process experience much higher spoilage rates. Printers who specialize in long-run, mass-circulation periodicals have much lower spoilage rates than do commercial advertising printers.

In spite of these difficulties in projecting the total amount of waste generated by the industry, analysis of the data will undoubtedly reveal consistent relationships. For example, the larger plants usually have long production runs with few changes. Conversely, smaller plants frequently specialize in shorter runs with many changes. We expect, therefore, that data will be consistent within various plant size groups for broad product categories. It is not expected that the geographic region will significantly affect the amount of waste generated, but it does affect the amount of waste that can be sold.

Although larger firms keep adequate records of their scrap, the smallest firms (for example, those having less than 20 employees) often do not. Consequently, the amount of waste generated by small printing plants must often be estimated by the interviewer from inspection of a wide variety of containers. Fortunately, the large number of small companies produce only a minor share of total industry waste; consequently this problem will have a relatively small effect on the study.

Collection and Disposal

Collection and disposal systems for solid waste are almost invariably organized according to the disposition of the material which is salvageable and becomes a secondary material and which is discarded.

The major salvageable waste is scrap paper. Internal scrap-paper-collecting systems may be highly automated or may be manual operations. The type of system is determined largely by the size of the firm and the amount of scrap paper to be collected. Large firms typically use vacuum systems leading from the production equipment, through shredders, to balers, where the paper is gathered and compressed into bales weighing approximately 1,000 pounds. In smaller firms, employees usually place scrap paper in hand trucks or bins that are moved to a collection point by a janitor. There, the material may be baled or may remain loose to await pickup by the scrap-paper dealer or the private collector. Frequently, in both large and small plants, the scrap paper is sorted at the point of origin into white unprinted waste and printed waste. White waste usually commands a much higher price on the market, but the additional return is balanced against the additional equipment and labor costs of the sorting operation.

Other than paper, the major salvaged materials are metal (metal printing plates, reclaimed silver, and dross), photographic paper and film, and wood. This material is manually collected in convenient intervals.

The usual procedure for collecting unsalable waste is to manually accumulate all kinds in a common container for pickup and disposal by a collection agency. Trash and garbage is collected in a wide assortment of barrels, bins, and compactors. Smaller firms commonly place their trash into bins or barrels that are picked up and manually dumped by the collector. Trash from larger firms is generally collected in mechanized devices such as Dumpsters or Packmasters. By far the most frequent collection agency is the private collector with whom the firm has a fixed-price contract for predetermined number of pickups per week. Sometimes smaller firms are able to use municipal collection systems and, very infrequently, firms may dispose of their own waste by either hauling it to a dump or by incinerating it on the premises. No cases of on-premises dumping or burying have been found and even incineration is seldom used.

The type of system employed by the plant for collecting and handling scrap paper depends largely on the nature of the local scrap market. The amount of internal sorting a plant may do depends on the quantity of material and local scrap-price differentials. Differing prices among scrap-paper grades may justify the expense of a relatively complex sorting and baling system. If the prevailing market is weak with relatively low prices, sorting and baling will probably not be economically feasible. In some sections of the country, there is no market for relatively small amounts of scrap paper, and consequently, the scrap is simply collected and placed with the plant trash.

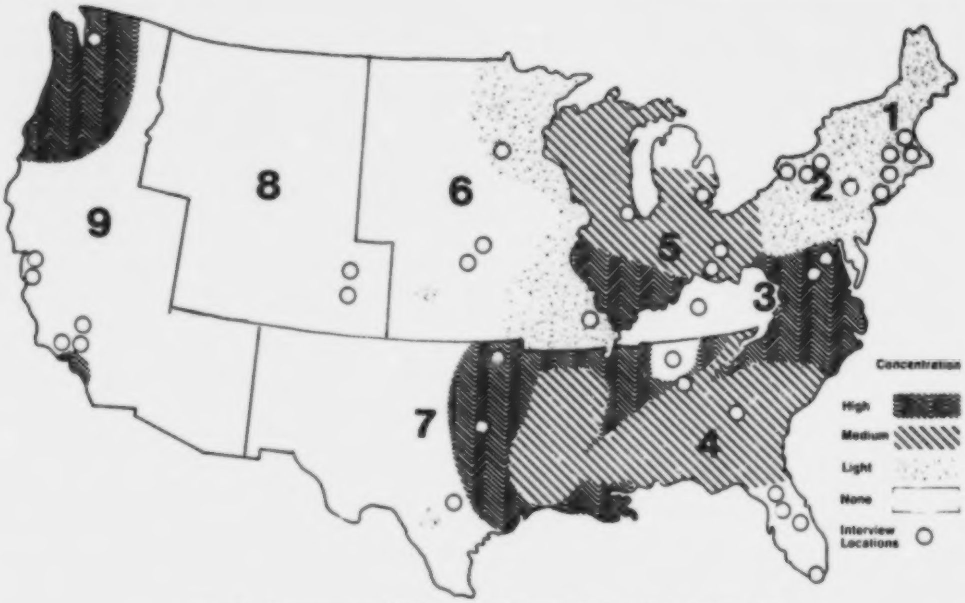

Figure 1: Concentration of Pulp, Paper, and Board Mills in the United States - 1969

Although the market for metals is quite uniform throughout the country, it has been found that the market for scrap paper varies widely among different geographic regions. This market of course determines whether the scrap paper is recycled or discarded. The strength of the market for scrap paper in any given location is primarily the function of the distance to the users, which are paperboard mills, newsprint mills, and certain building construction manufacturers. The most important of these users are paperboard mills. Consequently, the density of these board mills within any geographic region appears to be the best indicator of the strength of the local scrap paper market. Figure 1 shows the concentration of paperboard and paper mills throughout the United States. In areas of heavy concentration, the scrap paper market tends to be strong. Exceptions are the Pacific northwest and parts of the southeast where the ready availability of virgin pulp tends to reduce the value of scrap paper even though there is a heavy concentration of board mills.

Under present economic conditions, solid waste in the printing and publishing industry is not a serious problem to the nation. Although the proportion has not been determined, most of the industry's paper waste and practically all of its metal waste is recycled. Very few plants are large enough to have cafeterias, and consequently, there is little garbage. Much of the wood waste in the form of broken pallets and skids is eventually sorted out by the collectors for building material, firewood, and the like. The remainder of the waste does not appear to present any particular disposal problem as it contains few noxious elements. One exception is empty plastic chemical containers, which do cause difficulties in municipal incinerators.

Although their effect is uncertain, some future developments can be seen that may significantly influence the disposition of solid waste from printing and publishing. First among these are changes in the economics of the scrap paper and metals market. It is believed, however, that these markets will tend to grow stronger, and thus, improve the frequency of recycling. Another, and possibly more serious, development may be the increasing use of plastics instead of paper as printing substrates. At the present time, much of the scrap plastic from the printing process is saved and returned to the plastic manufacturer. The portion that cannot be reused does not appear to be large enough to cause disposal problems at present, but this may change in the future.

A Preliminary Report on Automotive Industry Solid Waste*

RALPH STONE
and
RICHARD L. KAHLE
Ralph Stone and Company, Inc.

In the early 1900's, the automotive industry consisted of many small vehicle manufacturers and parts suppliers. The trend toward consolidation of companies began in 1911. In 1970, only four major automobile manufacturers existed. In addition, there were over 2,000 parts and custom vehicle manufacturers, some of whom supplied the major manufacturers.

The first mass production assembly line was installed at the Ford Motor Company in 1913. Since then, the mass production assembly line has been improved by the standardization of parts, computer scheduling allowing several vehicle styles to be assembled on one production line, and the introduction of multi-station transfer machines, which automatically perform several machining operations.

The story of Henry Ford requiring his suppliers to ship their goods in wood containers made of boards of a specified size and quality, and then using the wood for floor boards in Ford cars is perhaps the first incidence of planned reclamation of waste materials. During World War II, materials shortages provided industry-side impetus for improved scrap and solid waste management. The large manufacturers began installing chip conveyors and crushers, balers, and machine oil recovery equipment.

In 1968, the industry comprised 2,526 plants, of which suppliers and custom truck manufacturers represented a minimum plant valuation of approximately $1,724,000,000. The bulk of the industry was located in the Midwest, with Michigan and Ohio containing the greatest number of large plants. Michigan was the highest vehicle producing state with 34 percent of total automobile production in 1968.

The rate of gain in productivity for industry workers over the short term from 1960 to 1968 was 0.14 percent per year, compared with the long term 1948 to 1968 trend of 2.9 percent per year. This trend change is the basis of recent (1969) comments by industry management that costs per vehicle have risen because of the lower rate at which productivity is increasing.

In the peak production year of 1965, over nine million cars and 1.7 million trucks were manufactured. The average number of hours worked per week by each employee was 44.2. For the period 1970-1975, the industry production is projected to be in the 13 to 15 million vehicle per year range.

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*This study was supported by the U.S. Department of Health, Education, and Welfare, Public Health Service, Environmental Health Service, Bureau of Solid Waste Management, under Contract No. PH 86-68-212.

Objectives

The objectives of the study were the following: (1) to determine the character of solid waste and scrap materials generated by automotive plants, (2) to identify the solid waste and scrap generation sources, (3) to determine handling, collection, and disposal methods and costs, and (4) to determine the effects of plant residents on the environment and community.

Procedures

Questionnaires were mailed to 1,700 automotive industry plants, requesting data concerning type and quantity of solid waste produced, and collection and disposal methods and their costs. Forty-three completed questionnaires were returned. In addition, questionnaires were also sent to municipal authorities in areas containing automotive plants requesting information on municipal solid waste disposal procedures and facilities. Forty-eight responses were received from the municipal authorities. Two hundred seventeen questionnaires were received from the Automotive Manufacturers Association (A.M.A.). Only the collection and disposal cost data from the A.M.A. questionnaires is included in this paper because of the short time elapsed since receiving the data.

To supplement the information on the questionnaires, 74 plants and nine municipal areas were visited by Stone Engineers. The items sought at each plant included: (1) product weights, solid waste and scrap weights, contractor costs, and recent or anticipated changes in management; and (2) plant layouts and process schematics noting solid waste generation and storage locations. The municipal authorities were questioned as to the relation between plant and municipal waste management practices.

Results

The types of solid waste generated in the automotive plants were classified as follows: metals (including ferrous and nonferrous), plastics, paper products (and cardboard), and wood. The sources for these wastes were the following: machine and foundry operations (casting, forging, machining, drilling, and grinding), trimming and cutting operations, offices, cafeterias, and packaging and shipping operations.

The most widely used storage receptacles at the waste source were 55 gallon drums. The majority of waste bins varied from 1.5 to 5 cu. yd. in size. In-plant waste collection involved one of six alternative pick-up methods: hand truck, tow truck, fork lift, small industrial truck (with rear carrying platform), belt conveyor, and vacuum system. Most plants employed hand removal to empty in-place containers in conjunction with a hand truck or industrial truck. When a tow truck was used, the waste bins had wheels and were hooked together and towed to the storage area for processing and collection. Vacuum systems were used for removing light sawdust, plastic interior trimmings, grinding dust, and paper trimmings. Conveyors were used for the removal of scrap metals. Most conveyors were part of complete scrap handling systems, which conveyed metal from the plant source to waiting railroad cars, gondolas, van trailers, or bins or directly to processing equipment such as balers and shredders.

The most widely utilized item for waste volume reduction was the compactor, the size of which varied from 8 to 80 cu. yd. The motivation for compactor use was the reduced collection costs for transporting the smaller solid waste volumes.

The major alternatives for disposal of solid waste were processing at the plant and utilization of disposal areas outside the plant. At the plant, the methods for waste disposal were incineration and landfill use. With the exception of foundries, where metal by-products were recycled for reuse, most plants sold their scrap to private dealers.

Although air pollution regulations are becoming more stringent (1970), large plants viewed incineration favorably. Large plants can better afford to install incinerators with air pollution control equipment than can small plants. The solid waste management policy of many plants was determined by the degree of enforcement of air pollution controls and the quantities of waste generated. The larger the quantities of waste produced, the more desirable incineration became. Plants utilizing landfills were generally located in urban California communities or in rural areas in the East and Midwest United States.

Ninety percent of the plants surveyed used private collectors to remove wastes from plant premises. The remaining 10 percent used public collectors. Regular collection schedules were used for waste removal in 83 percent of the plants surveyed and for scrap removal in 59 percent. The least frequently scheduled waste collection was twice a month.

Waste removal costs are plotted in Figure 1 for the combined data from A.M.A. and the parts and accessories manufacturers. The general trend is exhibited by the unit cost curve that shows decreasing solid waste collection-disposal cost per ton with increasing waste tonnage generated. The variation of solid waste generated with number of

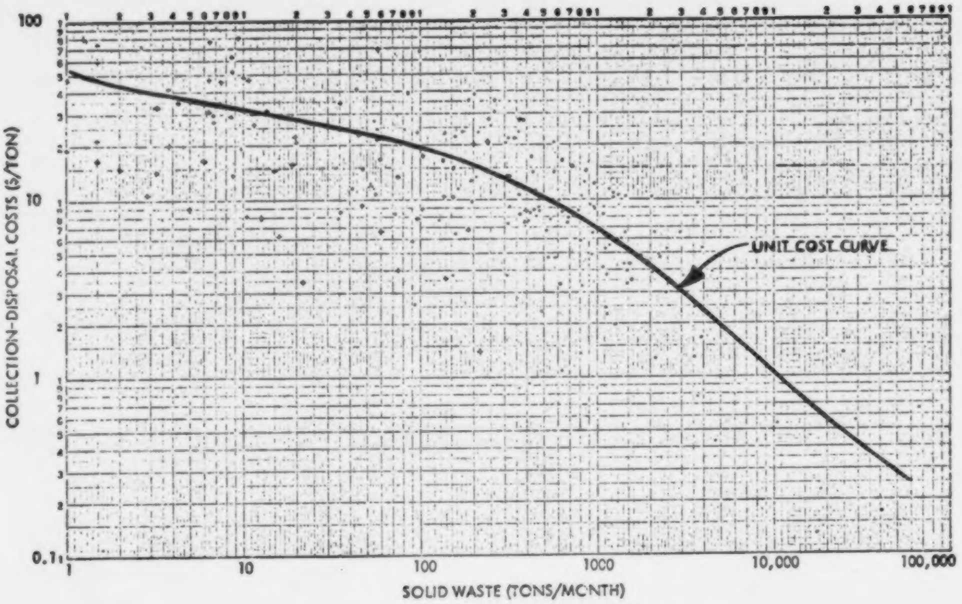

Figure 1: Solid Waste Collection — Disposal Costs

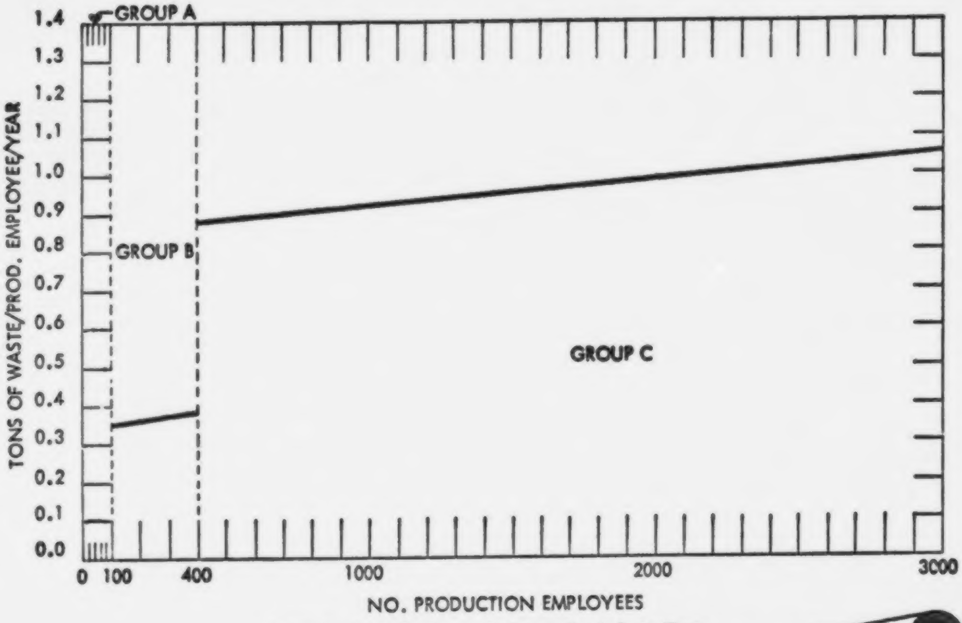

Figure 2: Waste Production In Automotive Industry Plants

Reproduced from best available copy.

production employees is shown in Figure 2. Waste generation quantities per employee fell into three plant employment groups for the parts and accessories manufacturers.

Most plant personnel questioned indicated they were satisfied with their handling and disposal methods. They believed solid waste control to be a management function requiring optimum economy. There appears to be a need to recognize that solid waste collection and disposal should be considered as a public utility, and that private collectors and haulers who have a monopoly over waste collection and removal may require regulation. Personnel from the large plants were more responsive to government regulations than were personnel from smaller plants.

Municipal authorities lacked dependable information on industrial solid waste disposal. There was little record keeping, especially regarding the quantities and types of solid waste from the automotive industry. However, communities that charged for the use of their disposal facilities had more complete records. Private contractors rarely maintained detailed records.

The automotive industry and the municipalities viewed each other's performance in handling solid waste as being satisfactory. The major problem cited by industrial personnel concerned lack of disposal sites.

Improved cooperation between industry and public agencies on all levels would be mutually beneficial with regard to waste management practices. For communities to adequately plan their solid waste disposal facilities, and also to serve industry, a knowledge of the quantities and types of waste generated from the industries within the community should be available.

ACKNOWLEDGEMENTS

We acknowledge the generous cooperation of Mr. Rodney L. Cummins, Project Officer. Mr. Henry T. Hudson, Staff Engineer, and Mr. George Garland, Staff Statistician, Bureau of Solid Waste Management, also provided valuable technical assistance. Many public and private agencies cooperated in the survey: both the Automotive Service Industry Association and the Automobile Manufacturers Association distributed questionnaires to their member firms; and many automotive industry plant and public agency personnel generously assisted our staff engineers' field surveys.

Solid Wastes Management Survey of the Household Appliance Manufacturing Industry*

LOUIS KOENIG
Louis Koenig Research

This progress report of the household appliance manufacturing industry describes the general economics of the industry and an approach toward a rational sample for the survey interviews. The Bureau of the Budget approval for the pre-test questionnaire has been pending and the field survey will soon begin.

This industry, SIC 363, is made up of seven 4-digit sub-codes described, in short, as ranges, refrigerators, laundry equipment, housewares, vacuum cleaners, sewing machines, and household appliances not elsewhere classified. The latter sub-code includes water heaters, both gas and electric, disposers, and dishwashers. The housewares sub-code includes electric space and wall heaters, but not central heaters, gas space heaters, or air conditioners.

The industry includes about 700 establishments with 170,000 employees and is highly concentrated in the north and northeast.

The specialization and coverage ratios are 85 percent. This signifies that the value of the Code 363 products manufactured by these establishments is 85 percent of (1) the value of all products manufactured by these Code 363 establishments and (2) the value of Code 363 products manufactured by all establishments.

The establishments about to be surveyed, then, manufacture products other than Code 363 products to the extent of about 15 percent, and also, to the same extent, Code 363 products are manufactured by establishments not in the Code 363 to be surveyed.

The survey plan calls for about 50 personal interviews to be followed by a short mail questionnaire to all establishments. The purpose of the latter is to check, without the expense of an interview, on certain characteristics, such as modes of disposal, that can be expected to have a geographical dispersion.

The industry is unusually highly skewed toward the large size establishments; most of the production is concentrated in a relatively small number of large establishments. To discover whether these large establishments have different coverage ratios than the industry as a whole, the number of SIC code products per plant were tabulated from information from Manufacturers' Directories. The ratio of the number of codes to the number of establishments averaged 1.8 and showed no variations with size. This indicates that, in general, establishments manufacture in one or two 3-digit codes, with no differences between the large plants and the small.

The three associations covering this field, the Association of Home Appliance Manufacturers, the Gas Appliance Manufacturers Association, and the Vacuum Cleaner Manufacturers Association, have been contacted. When one association expressed surprise that there were as many as 700 establishments (since they only had a few hundred on their member and prospect list), the number of establishments in the Manufacturers' Directories for 15 states was compared with the number of establishments reported by the County Business Patterns data for those states.

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*This project is sponsored by the U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Solid Waste Management, Contract No. CPE-69-4.

In the rational sample selection, some weight is being given to the types and quantities of materials reported to be used. The total materials input to the industry is about 2 million tons per year and is increasing at a historical rate of about 4 percent per year. This materials input amounts to about 13.5 tons per year per employee. An earlier, more general study of SIC 36 had projected a waste-for-disposal of about 1.35 tons per year per employee. This suggests that about 10 percent of the input materials find their way into the waste-for-disposal. Among the metals in the input materials, 92 percent are sheet and strip; 4 percent, castings; and the rest, alloy steel, copper, aluminum, and others.

The pounds of input material per unit manufactured varies from about 670 for ranges down to about 3 for general housewares. Some information from the trade journals and the Associations on the number of units sold each year indicates the number is not increasing greatly. Those expected to increase in the future happen to be those having a low pounds of materials per unit ratio.

Prospects of Utilizing Waste Glass

H. NEAL TROY
Glass Containers Manufacturers Institute, Inc.

Few, if any, industries are better able to utilize the waste materials from their own product lines than is Glass Containers Manufacturer's Institute, Incorporated. Our companies use a tremendous amount of so-called "waste glass" internally. It never gets outside of our plants to cause difficulty in any sort of waste disposal system. However, admittedly, a good deal of glass *does* get into such systems, because it is one of the most useful and most widely used materials in our country.

Glass, usually in the form of bottles or jars, is commonly found in the nation's ever-growing supply of litter, as well as in its solid waste. What's the difference? One of the most succinct definitions asks you to imagine throwing a piece of waste material at a convenient receptacle. If it goes into the basket, it becomes solid waste. If it misses, it's classified as litter. The point here is that we have to be concerned with the gathering and disposal of both.

It has only been lately, in fact only in this first year of the new decade, that solid waste and the other "pollutions" that soil the United States, have become truly "fashionable" — that is, sufficiently important and sufficiently publicized to warrant the all-out support of leading public figures and organizations. One of our greatest challenges is to make use of that strong support while it exists and to move forcefully and imaginatively ahead to an actual solution of the nation's solid waste disposal problems.

For the record, the glass container manufacturing industry has been working in this direction for more than two years. Things were quite a bit different even as little as two years ago. Industry did not really understand the difficulties and problems of government, nor did the government's solid waste experts understand clearly the problems of industry.

However, we have reached a point in time when all of us should be working closely with those in government who are responsible for waste disposal in order to gain a better understanding of our mutual problems. For example, it is only reasonable that producers of packaging materials should understand the problems their products may cause in waste disposal. Similarly, it is necessary that responsible officials understand industry's problems in supplying the consumer with modern packaging that he needs and demands.

Our own course has been to establish communication, which we feel has been very important both internally and externally in directing and coordinating useful research and development.

John Abrahams, whom many of you know, was appointed Manager of Environmental Pollution Control Programs for our trade association, the

Glass Container Manufacturer's Institute. The author of this paper is chairman of GCMI's technical subcommittee on environmental pollution control, which is made up of experts from throughout our industry.

The purpose of this paper is to try to give you a better idea of the progress we have made — to present a general picture of the scope and direction of activities being pursued by GCMI and its member companies, who represent more than 90 percent of the glass containing-making capacity of the United States.

The first point that should be made clear is the relative position of glass in the nation's solid waste disposal picture. Most people tend to be concerned about jars and bottles far more than they deserve in this context.

There can be no argument that *litter* constitutes only a tiny fraction of total wastes that must be disposed of. And glass is but a small fraction of litter, according to reputable surveys — only six percent, to be specific.

We have estimated that glass containers constitute perhaps 5 percent, by weight, of total "municipal" refuse and perhaps only 3 percent of municipal and industrial solid wastes combined. So, it is evident that our product fails to qualify as one of the leading, or even major, factors in solid waste disposal problems. However, it is a *factor*, and we are most concerned with its handling.

Let us remind you at this point that the title of this presentation is, "Prospects of Utilizing Waste Glass," and let us assure you that the prospects are excellent. To clarify this it is necessary to repeat and emphasize a point made by Jack Abrahams at the Second Mineral Waste Utilization Symposium sponsored by the Bureau of Mines in Chicago just last week. It is this — we already have discovered potential or actual uses for every scrap of waste glass available today. What to *do* with waste glass really is not the problem. How to *get* it — how to separate it from the jumbled bulk of other solid waste materials — *is* the problem.

The ultimate solution, of course, should be the separation of *all* the various components of waste and returning for reuse to their respective industries; which makes "separation" the major problem. There is no question either that the closer to the consumer the separation starts, the tighter the recycling loop and the more efficient the system.

Home separation was common in years past and a number of communities still practice it to varying degrees. More should do so. Even one separation of combustibles from non-combustibles in households and commercial establishments would open new avenues to salvage and reuse.

The reason we have been, and are, investigating a variety of uses for waste glass is that no single use is likely to be appropriate for all municipalities or disposal systems. What might be best for Houston could well be impossible for Boston. A New York City solution might be meaningless in St. Louis or Los Angeles.

The greatest requirement in *all* areas, of course, is improvement of the basic collection and disposal system itself. Money for improvement, or even for investigation of potential improvement, is severely limited because most of the available dollars already are being spent — 75 percent of the cost of solid waste disposal now goes to pay for labor and transportation.

But that is another story. This paper is concerned with the utilization of waste glass. Let us get into the work being conducted by and for GCMI so that you will better understand the background of that statement about being able to use all of the waste glass available.

First is our own use of waste glass. The nice thing about bottles and jars is that the moment they are discarded or broken, they are already in a reusable form. With little or no processing required, they can go right back into the furnace to help make more glass, without once leaving the factory.

Cullet Operations In-Plant

The events which this paper will describe should give you some indication of how waste glass, which is called "cullet" in the glass manufacturing business, is utilized within the glass container industry at the present time.

A rectangular batch tower is used for storing the batch materials in bins, and the equipment for mixing batch and also for handling waste glass or as we say "cullet." Broken or waste glass from production is stored here until it can be utilized back in the system. This material is taken from here to the area at the bottom of the batch tower, where it is conveyed to a crusher where the material is broken, elevated, and transferred across into a bin. Mixed batch material is overlayed on the cullet and conveyed through the screw conveyor to a bin. The discharge from this unit is into the hot interior of the furnace.

From the furnace the glass is brought out and formed into articles. The bottles are conveyed from the machine; from there they pass into the opening of an annealing lehr. When the ware being made on the machine has a sufficient number of defects, the articles can be short-circuited from there, down the chute to a collection point below. The ware comes out of the lehr, is picked up on the conveyor line, put in line, and then goes past and inspection station where several girls are seated. When there is defective ware selected by the girls, they are kicked off the back of the conveyor. The rejected ware from that station and other stations is carried on a conveyor belt, back in the direction from which it came. Rejects are dropped down a chute into a collection hopper. The glass is transported from this hopper back to the crusher area in the batch tower.

Summarizing this, the glass container industry is indeed set up to utilize its own waste glass.

Most waste disposal salvage systems operate with a combination of grinding or crushing, or with dry air and screen separation. At present, they also use a great deal of manual labor, because automation techniques simply have not been refined to the point of economic practicality as yet. The consequent high cost of labor has precluded more widespread acceptance of such salvage operations.

To give you a little better idea of the importance of these, there are only five or six cullet dealers in operation in the United States today. Within our industry we have to have our waste glass clean, washed, and color-sorted before it can go back into the production stream.

Minute amounts of colorants can affect the use of glass. With normal amounts of iron and chrome, it can be considered what we call flint, which means clear glass. With higher iron and nickle contents, a grayish cast is seen.

Other Uses

We will now quickly go over some of the many other feasible uses for reclaimed, recycled glass. First are building materials.

Lightweight building blocks are fabricated by the Bureau of Mines with Stanford University, using glass waste and lime. Structural building bricks are also made from waste glass by the Bureau of Mines.

Glass also seems to be finding a place in the paving operations, taking the place of crushed rock and becoming what we call "glassphalt." The technique was developed by the University of Missouri at Rolla under a grant from HEW, and its testing and development has been strongly supported by Owens-Illinois, Inc. in Toledo, Ohio and GCMI. The area to be covered in Toledo had a concrete base, with holes and broken spots. A tack cover was placed on the area to be paved. Standard machinery was used through the process.

Since most major cities have their own asphalt plants, it seems reasonable to assume that this sort of positive use for a now-wasted product may attract considerable interest. There probably is not enough waste glass produced in most cities to handle all of their regular paving programs, but undoubtedly there is enough to do a substantial amount of the pot-hole and other patching requirements. Another possible use for waste glass is glass wool, potentially good for insulation purposes.

We have to mention landfill sites, at which there can be no more stable base material than sand — which is what glass is mostly made of. Remember, a bottle *properly* disposed of has been broken and ground up until it loses nearly [illegible]0 percent of its original volume and can be packed very densely. In fact, in some states properly prepared waste glass has been accepted as highway sub-base materials. Solid waste landfill sites handle a mass of unsegregated and generally uncompacted waste. However, properly operated, it can be developed into useful land.

GCMI Research Program

Having established that there are, in fact, a great many uses for waste glass, GCMI established a three-pronged approach to the overall problem. First, we wanted to study various salvage and recycling procedures — both new and already established procedures — to ascertain their potentials as problem solvers. Second, we wanted to study old and new collection systems to establish their recycling and problem solving potentials. Finally, we wanted to help coordinate the work of communities and of other companies and interested parties by demonstrating the various things our own industry has done and is doing.

We have found that glass, as a material, is not a problem in present waste disposal systems. Preliminary findings of studies being conducted under our sponsorship at Drexel Institute of Technology in Philadelphia on the performance of glass containers in solid waste landfills show that if the glass is properly crushed, its volume is reduced to a minimum and there is no significant leaching. The fragments also do not rust, rot, mold, or pollute in any other way, and they contribute to a firm landfill.

Where incinerators are concerned, we find that glass bottles readily break up and help aerate the furnace charge, thus contributing to more efficient combustion. Also, since the glass is inert, it does not contribute to air pollution during the normal incineration process. To obtain glass-rich fractions of refuse for recycling back into the bottle-making process, we are supporting research by two organizations, the Stanford Research Institute and the Sortex Company.

At Stanford Research Institute a zig-zag air classifier is being used to make critical separation of mineral matter. After controlled grinding and shredding of refuse, the zig-zag design creates eddy-type currents beneath each projection, affording good control of separation by specific gravity.

Figure 1 is a line diagram of the system. The material is fed into the hopper on the left, then a

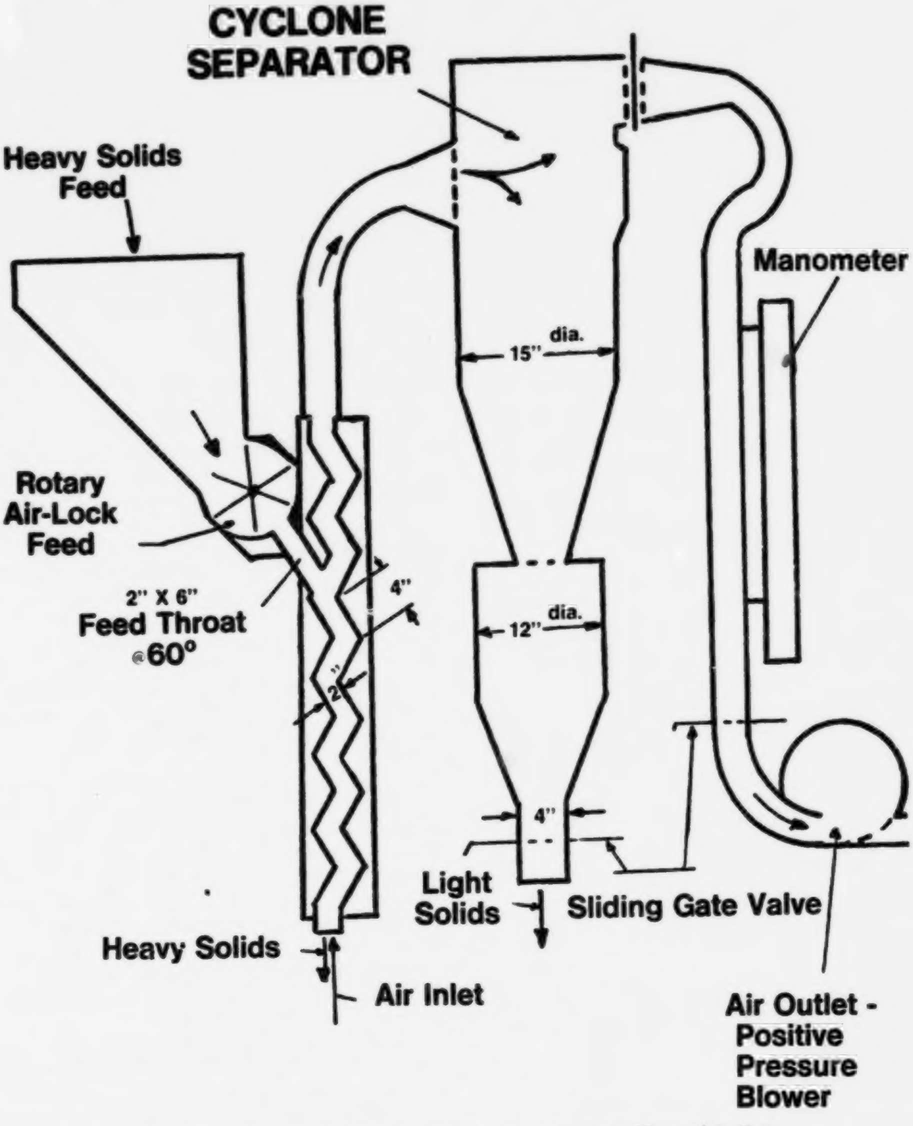
CYCLONE SEPARATOR
Heavy Solids Feed
Manometer
15" dia.
Rotary Air-Lock Feed
2" X 6" Feed Throat @60°
4"
2"
12" dia.
4"
Light Solids
Sliding Gate Valve
Heavy Solids
Air Inlet
Air Outlet - Positive Pressure Blower

Figure 1: Flow Diagram of Air Classifier as Developed by Stanford Research Institute

rotary air lock. Air is passed upward in the zig-zag portion. The light materials carry into the cyclone collector. The heavy materials are removed from the bottom of the zig-zag base and the light materials from the bottom of the cyclone collector. The sample would contain some metallic materials, primarily aluminum or copper, since a magnetic separation prior to the zig-zag separator removed most ferrous material.

Sortex Company of Michigan has developed an optical method of distinguishing clear, flint glass from colored glass at a rate of about one ton an hour on one sorting machine. Figure 2 is a schematic of the Sortex equipment. Its operation is to place individual particles onto the feed belts. The belt then projects the particle into space through the color sensing portion where the color of the particle is compared to the background. The particle is then either accepted or rejected on that basis, and its trajectory is changed by a blast of air. However, it is our belief that the operations can be refined to about the 97% level with one pass through the machine.

We have cooperated with the U.S. Bureau of Mines on its development of means of separating glass and metal fractions from incinerator residue. With color sorting and automatic removal of contaminants, which appear to be feasible, this glass, too, could be used as cullet to make new bottles. The finely ground glass fraction can be treated with a high-intensity magnet to remove the flint from the colored glass.

New methods and concepts for waste collection, salvage, and disposal are being developed by industry and need only the opportunity of full-scale pilot-demonstration programs in some typical community to prove their worth. One such is a unique wet system known as the Fibreclaim, an invention of Black Clawson of Ohio, which was reported on in detail at this conference. GCMI is working with various research organizations to further refine glass from this process for

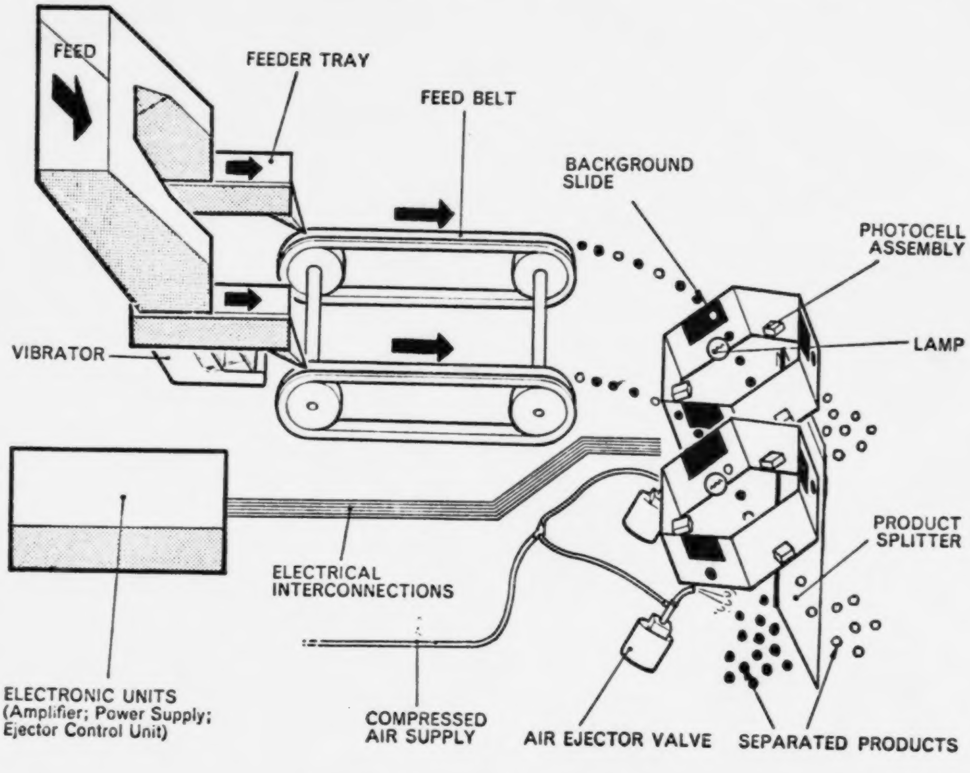
FEED
FEEDER TRAY
FEED BELT
BACKGROUND SLIDE
PHOTOCELL ASSEMBLY
LAMP
VIBRATOR
PRODUCT SPLITTER
ELECTRICAL INTERCONNECTIONS
ELECTRONIC UNITS (Amplifier; Power Supply; Ejector Control Unit)
COMPRESSED AIR SUPPLY
AIR EJECTOR VALVE
SEPARATED PRODUCTS

Figure 2: Schematic of the Sortex Equipment

reuse in glass furnaces. Glass removed from a hydropulper used in the production facilities of a reuse paper mill can be color-sorted relatively easily. The glass particles are considerably larger than that of the other systems. The Sortex color sorter can handle much larger rates of material if the particles are larger. Another source of glass could be reclaimed from a salvage composting operation such as the one operated here in Houston by Lone Star Organics.

The container glass industry is working toward not only utilization of its waste glass within its operations but utilization of waste glass from sources outside of its operation. As a matter of fact, we believe that as much as 50% of our raw materials from manufacturing glass containers could consist of salvaged, recycled, and crushed glass.

All in all, we estimate that from 20 to 25 new refuse management systems presently are in varying stages of development in the private sector. These include volume reduction by high-temperature incineration with a potentially reusable slag by-product, composting methods, and salvage techniques that recover some or all usable materials in refuse.

Studies we have underwritten indicate that most bottles and other glass containers are not normally broken, as they should be, at the point of collection and before disposal. Neither have trucks been designed specifically to handle the high density and consequent heavy weight of broken waste glass. We are interested in development of techniques and equipment to accomplish these desirable ends.

In seeking final solutions to the national problem of solid waste disposal, we should keep in mind that it is essentially a materials handling problem and not one of health control. Any program should be administered by people knowledgeable in materials handling technology.

If large-scale government funds are made available, as seems likely, they should first be used to stimulate immediate research in recycling and reuse of solid wastes, and in setting up pilot plants at key points across the country. The funding program should include several approaches, in this order: wet separation and dry separation for salvage purposes; high-temperature incineration, compaction, or composting for volume reduction; and design improvements in standard incinerator and pyrolysis units. Landfills should be used only to bury the unusable by-products of these processes.

After the feasibility and efficiency of the various methods have been scientifically determined, municipalities should quickly decide which techniques will be most appropriate to a solution of their particular problems. This will allow time for completion in design and construction of waste disposal systems that can function at the lowest possible cost and highest possible efficiency.

But we must begin! It will take 18 months or more just to build pilot projects of new systems, let alone establish national guidelines for solid waste collection and disposal. A new partnership must be established between government and industry — all industry — to get the necessary projects and programs rolling.

Shredding Plus Incineration, a Tandem System

LEONARD S. WEGMAN, P.E.
Leonard S. Wegman Company, Inc.

Buffalo

Buffalo is at the hub of the Niagara frontier in western New York. It is at the eastern end of Lake Erie and was founded before 1784. It is now quite a railroad center and is reported to have the largest flour milling and grain distribution facilities in the world. The City became a world port with the opening of the St. Lawrence Seaway in 1959. The City is currently in the midst of a major development program and its metropolitan area universities include the State University at Buffalo which is about to build a new $130 million campus in suburban Amherst.

Buffalo Refuse Disposal

Buffalo has a long history of incinerating municipal refuse. Its first large plant was built in 1928 as a 600 ton unit well qualified then to handle the one-half to three-quarters of a pound per day per person of municipal refuse. The City's second incinerator was built in 1953 at Squaw Island on the Niagara River to serve the west side of Buffalo. Although its rated capacity was 400 tons, its receiving bin limited operation capability to about 75% or 300 tons daily. Recognizing in 1959 that major changes in the entire pattern of refuse production were taking place, Mayor Frank A. Sedita began to plan ahead and engaged our firm to make a comprehensive study of the City's refuse disposal needs. Excluding bulk refuse, the 1959 per capita production of refuse was slightly under 3 pounds per day per person.

The Plan

The City adopted two of our recommendations: the bulk-heading of the Niagara River edge of Squaw Island to create a new residue area, and the enlargement of the West Side plant, including an air pollution control system for the 3 existing furnaces.

The City's goal for Buffalo was to convert an existing batch fed incinerator, with negligible air pollution control equipment, and an island refuse dump which received all bulk items, as well as incinerator residue, into a new incinerator complex which would perform to the highest current standards of avoiding air and water pollution and, at the same time, would conserve land by processing all bulk refuse to reduce it to its smallest particle volume of incombustibles.

Main Design Features

To accomplish these objectives, our design incorporated the following main features:

(a) A furnace configuration sized to accommodate the heat released from the increasingly higher heat value of today's refuse, and for refuse which will range in size from normal domestic household waste to large discards such as upholstered furniture, desks, tables, TV cabinets, and the like.

(b) A 3-level traveling grate stoker with independent speed controls to achieve dwell time, agitation, and burn-out.

(c) A separate chamber immediately downstream of the furnace designed for processing slow burning bulk items such as tree stumps, heavy demolition lumber, and the like. This chamber is also used for cremating dead animals.

(d) A 5-stage air pollution control system designed to equal or exceed the requirements of Federal, County, State, and local codes, It provides the following:

(1) A tortuous passage configuration to aid gas mixing;

(2) An increased burning length to maintain high temperature for a longer dwell period.

(3) A low velocity chamber which promotes gravity settling of large particles from the gas stream.

(4) High pressure tower and curtain water sprays to lower the temperature of the flue gases for removal of the next smaller particulate sizes and trace gases.

(5) Variable capacity, large diameter cyclone collectors which remove all of the remaining solid particulates, some as fine as talcum, from the gas stream required to comply with air pollution codes. The collected particles from the cyclone system discharge through rotary valves to a sluice-way system connected to the wet bottoms of the upstream combustion chambers. Flushing nozzles aid in transport of the flyash slurry to an in-plant pumping station from which the slurry is moved to settling lagoons and to the final disposal area.

(e) A system of automatic instrumentation using color-coded loop controls with manual overrides to govern furnace temperature, flue gas cooling, and cyclone collector efficiency.

(f) An emergency generator to protect the plant against failure of electric power or water cooling.

(g) A drag conveyor and a water trough alined to serve both the furnace and bulk burning chamber for removal of residue to a truck parked within the building.

(h) An air pollution control system for the existing batch fed furnaces similar to that for the new furnace.

(i) A bulk refuse crusher capable of crushing and shredding bulky articles: sofas, mattresses, refrigerators, crates, tree trunks and limbs, all into pieces 6"-18" long. The crushings can be fed into the existing batch fed furnaces so that all bulk items can be incinerated, an operation that was previously not possible.

(j) Refuse receiving and storing bins tripled in capacity.

The Crusher

There are so many interesting features of the Buffalo plant it is difficult to single one out before the others, but this paper will discuss shredding. The crusher's purpose is the processing of bulk items, particularly tree trunks, into a form acceptable to the older batch fed furnaces, or equally acceptable to the continuous feed mechanical furnace, the idea being to avoid consumption of furnace capacity by what otherwise would have been long-time burning of a very slow burning item, probably complicated also by the problems of residue discharge. After the main construction contract was prepared, the Federal Government advised that they would approve our application that they underwrite 2/3rds of the cost of a new type of crusher as a demonstration grant.

Now came the problem of selecting the crusher type. At the time of design selection there was no United States crusher performance data on which we could rely. Although this project was supported by a Federal demonstration grant, we wanted, nevertheless, to rule out as much as possible any chance of poor performance.

Europeans had progressed crushings much farther than we had in 1966. The European Company which showed the greatest success in crushing bulk refuse was Hazemag, and members of our staff had witnessed the operation in Amsterdam and elsewhere. Nevertheless, before Hazemag was finally approved for this installation, we sent a team to monitor the operation of a prototype unit at Hamburg, West Germany. We incorporated a number of improvements in the installation as a result of that trip, but basically we were satisfied with the unit's performance in Hamburg.

Crusher Statistics

The bulk crusher has a capacity of 250 cu./yd. per hour. It utilizes a 400 HP motor which drives a 62" diameter fixed hammer rotor at approximately 700 rpm. The hammers drive the item to be crushed against 2 suspended plates resulting in a crushing, tearing, and shredding sequence. The charging hopper is 7 ft. wide by 15 ft. long and has a vibrating feeder which sorts the material as it is fed into the hopper compartment. The feed opening is 5 × 12. Crushings fall through the machine onto a second vibrating feeder, from whence it passes to an inclined conveyor which takes the crushings up to the crushings bin.

First Phase in Operation

The entire project is being constructed in 2 separate phases. The first and major phase was completed in October 1969 and has been in continuous operation for the past 3 months. Although the 3-level continuous feed furnace has a rating of 200 tons per day, it has been performing at a rate of close to 300 tons per day and producing a superior residue. The bulk burning chamber has been handling animal carcasses and slow burning items as needed.

For the time being, the use of the crusher will be limited because of the limitation on available furnace capacity. Late next month we expect that the 3 batch fed furnaces will be ready for operation, having been connected to the new air pollution control system at that time. It is interesting to note that the single 3-level traveling grate furnace has been handling about the same volume as the 3 older batch fed units.

Direction of the Program

Overall direction of the entire program is by John F. Downing, P. E., Buffalo's Commissioner of Public Works. Commissioner Downing, of Buffalo, has been moving aggressively, not only in incineration and shredding, but also by exploring the practicability of transfer stations, remote landfill, and composting.

After a study and request for formal bids for composting, rail haul, compaction, and truck transfer, Commissioner Downing recommended that the City build a compaction truck transfer station capable of receiving all types of solid wastes. The refuse will be hauled by contract to a remote sanitary landfill in Erie County outside the Buffalo city limits. As an experiment, the city's plan is to confine the truck transfer station system to the east side of Buffalo. However, the West Side Incinerator complex stands as the backbone of the City's refuse structure.

Tests

Full-scale tests have not yet been made on the air pollution control system pending the completion and operation of the system for the existing furnaces. However, sampling of the dust collection during operation of the new furnace indicates that it will easily meet code requirements. The system has been patterned after a prototype at Roslyn, New York which exhaustive independent tests showed to far exceed the requirements of the State Control Agency.

Credits

Construction was by contract to Plibrico Company of Chicago and Hendrich of Buffalo. The traveling grate stoker was supplied by Illinois Stoker Company. Planning, design, inspection of construction, and assistance during operation were performed by Leonard S. Wegman Company, Inc., of which Herbert W. Thomas was Project Manager and Cedric Wood, Resident Engineer.

SUMMARY

While our judgement must necessarily be based on just a few months of operation, it is our conclusion that this project can be considered notable for the following reasons:

(1) It has demonstrated that, by use of the shredder, the bulkiest combustible refuse can be processed to make it suitable for any type of modern municipal refuse furnace, including those furnaces with batch charging and relatively small charging openings and discharge hoppers.

(2) By such shredding ability, it will conserve land, because bulk combustible refuse can be reduced to its inert ash component and such metal boxes as refrigerators, washing machines, and the like can be reduced to minimum volume suitable for metal decomposition in residue, or for salvaging of raw metal.

(3) The 3-level variable speed traveling grate is an effective and dependable stoking method, superior to the 2-level unit.

Designing a 6,000 Ton per day Refuse Incinerator for Steam Production

LEONARD S. WEGMAN, P.E.
Leonard S. Wegman Company, Inc.

The Project

The East River Environmental Protection Center in New York City will combine the world's largest steam generating refuse incinerator, 6,000 tons per day, with a 70 mgal/day wastewater treatment plant. The following discussion is based on design assumptions and options developed to date during study and preliminary work.

Refuse Demand

New York City now discards 23,000 tons of refuse each day. Only 8,000 tons are processed in post-war incinerators, all built subsequent to 1950. For the other 15,000 tons, the City, like all urban centers, is almost devoid of landfill. It must rapidly convert to an efficient reduction process to meet the looming surge of solid waste. This plant, and another under design by Metcalf and Eddy, will more than double existing incinerator capacity.

When the Brooklyn Navy Yard stopped operations as a naval installation in 1967, the City acted to designate a portion for what was then foreseen as a separate incinerator and sewage plant facility. Our firm was engaged to study the feasibility of building an incinerator on the site.

Design Study Parameters

At the very outset, New York established six major parameters for the study: 1.) there shall be full compliance with all applicable pollution control codes; 2.) environmental and vicinity aesthetics shall have prime consideration; 3.) the treatment plant and the incinerator shall furnish the maximum practical assistance to each other, considering economy and pollution control goals; 4.) the site for both refuse and sewage shall be limited to 18 acres in the northwest corner of the former Brooklyn Navy Yard. This size limitation had a profound effect on the plant; 5.) refuse shall be assumed to have a heat value of 6,500 BTU per pound; And, 6.) the maximum refuse capacity for which the site is suitable shall be sought.

Concept Development

Commissioner Maurice M. Feldman, P. E., of the City's Department of Water Resources, conceived the idea of a combined wastewater treatment plant and incinerator. As this imaginative concept developed, it is interesting to note how, in many respects, the project was, in microcosm, a reflection of current urban life.

Navy Yard Goals

For one, the Brooklyn Navy Yard adjoins a low-income area, and the City's intention is to redevelop the yard as a source of new employment. Next, the City joined with private agencies to establish the CLICK organization to develop industry in the Yard. Then, the City found itself in a somewhat friendly competition for use of the Yard's space. In the interests of maximum jobs, the City minimized the land area for the combined environmental protection center and, after lengthy negotiations, the entire center was limited to 18 acres. Thus the Yard will help the struggle against poverty and pollution.

Aside from the design problems caused by the basic limitations of space, the site offered several main advantages for the center. It lies near the City's geographical center on the East River, where it can be supplied entirely by barged refuse. Immediately adjoining is Consolidated Edison's Hudson Avenue generating plant which makes steam for the company's commercial customers across the river in lower Manhattan, perhaps the world's most important financial center.

Plant Size

We concluded that the site could accommodate a 6,000 ton-per-day containerized refuse incinerator and a 70 to 120 million-gallon-per day wastewater treatment plant, with more than the usual environmental benefits. Two million persons will be served by the incinerator and 400 to 600 thousand persons by the treatment plant.

Plant Function

Important economies in pollution reduction will come from coordinating incinerator and wastewater treatment plant functions:

(a) Screenings, skimmings, and grit with high organic loadings which are now trucked from treatment plants to refuse landfills can be deposited at the new refuse truck transfer station into containers and thence directly into the furnace;

(b) The forced air requirement for the furnaces offers convenient means for removing and disposing of sewage tank contact air;

(c) Sludge disposal at sea, now a subject of earnest public discussion, may warrant a change to higher cost incineration, which may be offset by better reduction of volatile solids in the furnaces;

(d) Fly ash transport, nozzle thrusters, quenching, and cooling will use sewage effluent;

(e) Waste heat may be available for direct steam drive of plant components;

(f) Adjacent Con Edison condensing equipment offers an economy in city water consumption.

Site Dependability

Dependability is a most important element for this project, as it is for most any incinerator project. The city must be able to process refuse. All other design considerations must be subordinate to that basic plant mission. But that very dependability also serves the development of a sale of steam to the utility company. They, too, are vitally concerned with dependability. Our backup sources, should refuse be unavilable or of too low a heating value, will be natural gas and fuel oil.

Refuse Handling and Charging

Traditional practice in the incinerator industry, both in the United States and Europe, has been to move refuse into a receiving bin and then via a bucket to the furnace charging hopper. This may be a satisfactory system for furnace capacities up to 400 tons per day. At the 750 tons per day for East River, each furnace, at the peak rate of 37.5 tons per hour, will need some 15 charges per peak hour, allowing a 4-minute cycle per charge. This drops to 3.1 minutes per charge when allowance is made for slowdown near the bottom of the barge. We concluded that this cycle time could create feeding problems.

Refuse Containerization

Methods of transporting and handling cargoes have undergone almost revolutionary changes within the past five years. Now a loaded barge can move on the Mississippi river to the LASH ship, be hoisted aboard at New Orleans, refloated at Rotterdam, and then travel via canal to inland European centers. The ship's on-board gantry crane can lift and stow a 510-ton barge in 15 minutes. These developments, coupled with East River's cycle restraints, led us to study the handling of refuse in containers. We found many advantages:

(1) Complete enclosure of the refuse load during all phases;

(2) Improved fire safety;

(3) Prevention of spillage and scatter;

(4) Adequate feeding rates for up to 1,000-ton-per-day furnaces;

(5) One 50-ton container lift will replace 15 to 25 bucket lifts; and

(6) Rapid turn around around of barges.

After studying nearby container operations in New York harbor, consultation with the leading manufacturers of container equipment, and our own independent analyses, we concluded that our proposed containerized refuse system presented no demands exceeding present technology. While the hardware for refuse containers needs design and pilot testing, the entire container technology had advanced so far that the feasibility of this method is no longer in question. If one might look ahead, we can visualize containers being loaded within major in-city buildings. If held in refrigerated compartments, they need be moved only once a week and then only to the municipal incinerator, where the container can be unloaded directly into the furnace. Think of the saving in labor costs and the elimination of the undesirable aspects of street loading from the collection process.

Refuse Movement Aesthetics

For some years, the City has been moving refuse in open barges. A national magazine recently photographed one of these refuse barges with the Statue of Liberty as a backdrop and had the legend note that New York City's garbage was going to sea. We all know that it's not. Nevertheless, the public is as much concerned about pollution of the view as about other pollutions. Thus, covered containers in barges offer one more advantage.

At the plant, the containerized refuse will be enclosed and protected to a degree well beyond traditional practice. During all phases of in-plant movement, receipt, storage, hoisting, and furnace charging, refuse is out of sight and not subject to fire hazard and otherwise inevitable casual spillage and litter. When the refuse leaves the container, it will be transmitted directly to the hopper below, restricting any tendency for refuse particles or dust to escape into the plant environment.

Steam Generation

Steam generation offers opportunities and challenges. Six thousand tons per day of today's municipal refuse frequently has a heating value equal to 3,000 tons of coal. We are going to obtain revenue from this otherwise wasted heat and also help meet our air pollution abatement goals. We estimate that the air pollution resulting from the particulate emission from burning 3,000 tons of fossil fuel, and equivalent obsolete refuse incineration, as at local apartment and in-building sites, would total 10,000 pounds per hour of particulates. We anticipate that the provisions for steam generation and the sequence we have developed for air pollution control would yield an output of the order of less than 100 pounds per hour from the East River plant, a source reduction of 98 or 99 percent. In terms of the air pollution performance of the plant itself, relative to its own capability, we anticipate a reduction in the order of 99 to 99.5 percent. Steam generation helps us accomplish this because the heat exchanger for the boiler will extract about 50 percent of our particulate loading. Also, by cooling the gasses, it will allow us to use smaller downstream flues, conditioning chambers, and, as presently contemplated, electrostatic precipitators. For the problem of corrosion, we are investigating tube material, gas mixing, point of flame impingement, metal refractory, and air shields, and the possible use of additives to the fuel mixture.

Steam Statistics

At 6,000 tpd and 6,500 BTU refuse, we will produce 2,000,000 lb. of steam per hour at 450°F and 400 psig. Our in-house demand has been tentatively set at 25 percent and we anticipate an income in the range of $4,000,000 per year for marketed steam. Our initial back-up fuel will be natural gas, purchased at the interruptible gas rate. Secondary fuel will be #4 fuel oil, for which we will maintain 500,000 gal. in storage — about a two-day supply. While the volume of steam to be sold to Con Ed and the prices have not yet been negotiated, the range of return is equal to half or more of the annual plant operating cost.

Back-up Equipment

As you will shortly see from a study of the cross-section and the general plant layout, each critical element has a back-up facility. Each of the eight furnace trains is completely independent, with its own charging hopper, furnace system, boiler, conditioning chamber, electrostatic precipitator, induced draft fan, flue, and stack. There is a reserve supply crane and a reserve residue conveyor, so that we can tolerate for each of the two furnace banks a 50 percent outage on cranes and a 50 percent outage on residue removal, and still keep the bank in full operation. With containers, we have a variety of storage systems available to us for storage of refuse, as during weekends and holiday periods, the plant will operate seven days a week, 24 hours a day.

Residue Reuse

We are much interested in recent experiments by the U.S. Bureau of Mines on the classification of incinerator residue into various raw material components such as ferrous metal, aluminum, and glass. We have had some initial contacts with a firm which would like to reprocess our residue to remove metals. As for the value of steam generated by this plant, this is another economic benefit to the city.

SUMMARY

Thus, the East River Environmental Protection Center integrates wastewater treatment with refuse incineration and will effect a recycling of the refuse to a useful purpose, in that the heating value of the refuse will be recovered and the comparatively uncontaminated raw material in residue can also be reused for other purposes.

CREDITS

As noted earlier, Commissioner Maurice M. Feldman, P.E., was the guiding spirit of this plant and concept. The major development of the preliminary planning was performed under the administration of Dr. Merrill Eisenbud, P.E., Environmental Protection Administrator. Directly in charge of the design development for the City was Martin Lang, P.E., Deputy Commissioner of Water Resources, and Joseph Cunetta, P.E., Assistant Director of the City's Water Pollution Control Office, assisted by Anthony Cuciti, P.E., of the Sanitation Department, and Abraham Brenner, P.E., of Water Resources, Hazen & Sawyer, of New York City, did the preliminary design of the wastewater treatment plant and will do the final design. The Parsons-Jurden organization will be the City's overall consultant for the Environmental Protection Center. Leonard S. Wegman Co., Inc. developed the original concept and the incinerator facility report and will perform the detailed design of the incinerator and steam generating system. Herbert Mandelbaum, P.E., Vice-President of the Wegman firm, is the project manager. Assisting him are Roger G. Burns, P.E., Chief of Mechanical Design, and Henry Liebman, P.E., Chief of Waste Management Services for Wegman.

The Cost of Municipal Incineration*

LOUIS KOENIG
Louis Koenig Research

This paper presents some highlights resulting from a comparative cost engineering audit made on incinerator plants in 1968-1969. The term "cost engineering audit" means a detailed investigation and analysis of the physical characteristics, the operating data, and the costs of plants or other operating installations, and the presentation of these in a standardized manner so that internal and external comparisons may be made. The study has been reported in a final report on the project which was sponsored by the Bureau of Solid Waste Management.

The study had a number of objectives and purposes, but one of the major ones was to present data so that an incinerator manager could compare his operation with those of other plants to determine how his performance compared with others, and so that he might take remedial measures if desired.

The full report covers some 120 items of information on the 23 plants; only the highlights and conclusions from the analysis which are thought to be of particular interest to this audience are presented here.

Among 120 items were: elements of the design of the plant, including the design manpower; the unit prices, such as those for investment, labor, materials, energy; production factors (various operating ratios); unit consumptions of labor and materials; and unit costs, including labor costs by category of labor.

Incinerators of relatively recent design and construction were chosen for the sampling so that their use might be expected to continue in the immediate future. Studying the types of incinerators that are to be built in the future, which include such things as water walls, heat recovery, and advanced air pollution control devices, would be desirable, but not enough of these types exist to constitute an adequate statistical sample. The criteria were as follows: bin and crane receiving and feed; tipping floor, closed or open; continuous feed; refractory wall, primary fly ash collection by a wet system; residue conveyors; and treatment of waste water; but no heat recovery or no sophisticated air pollution equipment such as electrostatic precipitators, etc. These criteria were relaxed for a few incinerators in the sample to check whether their absence or relaxation made major differences in the costs.

The original sample contained 22 municipal incinerators and one merchant incinerator that operated on municipal waste. Eighteen were traveling or rocking grate, three were rotary kiln, and two were batch cylindrical. The design tons per day ranged from 150 to 1,000; the actual production tons per day ranged from 25 to 700. To the original sample, one 1,000 ton per day incinerator constructed in 1953 was added. One other incinerator had been constructed in 1953. One other incinerator had been constructed in 1955 and the rest between 1958 and 1967. During this period, about 100 incinerators have been installed in the nation, so the sample represents about 20 percent of these. Of the 100 actual installations, only four are larger than the 1,000 ton per day (largest in the sample), and only four are less than 150 ton per day (smallest in the sample).

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*This work was performed for the U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Solid Waste Management, under Contract No. 86-68-164.

The analysis, made as an aid to comparison, first explored whether each data item was correlated with size of plant — either with the design capability or with the average production rate. If it was not so correlated, then the analysis determined the median value and the distribution of the sample values around this median. The report gives 10, 50, and 90 percent level of the population (the slope of the frequency distribution) so that the value at any percentile level can be found.

If the data item was correlated with size, the statistical regression line representing the correlation was determined, as well as measures of how the sample points were distributed about this line. The report gives the regression line values at 100 and 1,000 tons per day for either capability or production. From the data and methods provided in the report, an incinerator manager can determine at which percentile level his operations fall for most of the 120 elements.

Table 1 shows the median cost level of the five major cost elements in plants producing 100 and 1,000 tons per day. These costs are taken from the regression line at these production rates; they are the medians of the distribution where there was no correlation. For example, the median plant producing 100 tons per day can be expected to have a labor cost of 271¢ per ton. The total operating cost of such a plant, which is median in all cost elements, will be 366¢ per ton. The capital recovery at the actual utilization factor attained will be 200¢ per ton. The utilization factor is the ratio of the actual production rate to the design capability. The total cost at the actual utilization factor, namely the sum of these five components, will be 567¢ per ton. In the 1,000 ton per day median plant, the corresponding total cost is 300¢ per ton.

In both sizes, the major cost components are labor and capital recovery. Labor is about 48 percent of the total cost in both sizes and capital recovery about 35 percent for the 100 ton plant and 25 percent for the 1,000 ton.

The "10 Percentile Plant," data show what the costs would be if the unit costs in the two major components, labor and capital recovery, were reduced to the level of the 10 percentile plant in

TABLE 1
Costs in Median and "10 Percentile" Plants

	Median plant				*"10 Percentile plant"*			
	ton/day = 100		*ton/day = 1000*		*ton/day = 100*		*ton/day = 1000*	
	¢/ton	*% of Total cost*	*¢/ton*	*% of Total cost*	*¢/ton*	*% of Total cost*	*¢/ton*	*% of Total cost*
Labor	271.2	47.9	144.2	48.1	168.2	43.9	89.4	41.8
Energy	29.8	5.3	12.9	4.3	29.8	7.8	12.9	6.0
Water	14.1	2.5	14.1	4.7	14.1	3.7	14.1	6.6
Maintenance, repair, and replacement	38.8	6.8	38.8	12.9	38.8	10.1	38.8	18.1
Miscellaneous	12.9	2.3	12.9	4.3	12.9	3.4	12.9	6.0
Total operating	366.8	64.7	222.9	74.3	263.7	69.0	168.1	78.5
Capital recovery at actual $\overline{U}$*	199.9	35.3	77.1	25.7	119.0	31.1	45.9	21.4
Total cost at actual $\overline{U}$	566.7	100	300.0	100	382.7	100	214.0	100
Percentage of median plant cost				67.5				71.3

*Utilization factor, ratio of production rate to design capability.

those components. For both sizes of plant, the total unit cost would be reduced by about one-third. This is about the limit that can reasonably be expected for improved performance, short of drastic process changes.

As an example of the nature of the basic data, Figure 1 presents the data points for the unit investment in dollars per ton per day of capability. The term "1967 National" on this unit investment signifies that all of the cost data have been deregionalized to the national average by using the Engineering News Record Building Cost Index and have been adjusted to 1967 levels by the Chemical Engineering Chemical Plant Cost Index. These data were explored for a correlation between unit investment and nominal capability, and indeed such a correlation was found—trending in the wrong direction. From the points shown, an eye line would indicate the unit investment increases with increasing capability instead of decreasing, as is almost universal with other process plants. This situation was so anomalous that a careful inquiry was made as to what characteristics of the sample or what errors would have to be involved for this anomalous behavior to be certified as real.

First note that the two batch plants, which have relatively low investments, occur at low capabilities, whereas the three rotary plants, which tend to have high unit investments, occur at high capabilities. If batch plants indeed have lower unit investments and if rotary plants indeed have higher unit investments, then placement of these plants at these capabilities would swing the regression line toward the anomalous positive slope. When the rotary and batch plants were eliminated from the regression line, the statistical results with the remaining points showed no correlation of unit investment with nominal capability, and showed a median of about $4,300 per ton per day capability.

This zero slope is still anomalous when compared with the vast majority of process plants, but continued intensive analysis failed to reveal

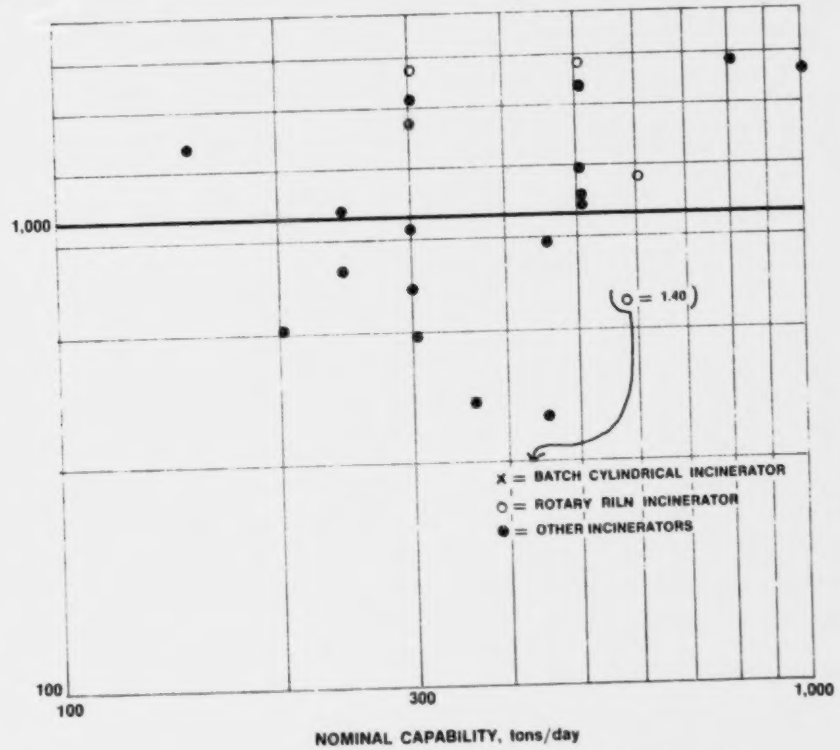

Figure 1: Unit Investment of 23 Incinerators in Dollars Per Ton Per Day of Capability

any unreality in the data. For example, if the cost indexes used for trending had been in error, and if it had happened that the larger plants were the newer plants, then the sample taken from a population with a negative slope could itself have shown a zero slope. But statistical analysis showed no correlation between size of plant and year of construction in the sample, and furthermore, the cost indexes would have had to be in 100 percent error to account for the magnitude of the presumed anomaly. Finally, it was learned that the 1968 National Survey of Community Solid Wastes Practices also revealed a similar anomalous trend of unit investment with capability for incinerators.

The quite surprising conclusion then is that there is no scale economy in investment in incinerators.

Since this is such a striking conclusion, it may be well to attempt, at the sacrifice of pure statistical accuracy, to explain the significance in nonstatistical terms. The notation σ =1.40 measures the degree of dispersion of the data around the constant line at 4300; the higher the value, the greater the spread in the data. A value of 1.4 is actually rather good for survey of this type of economic data. A σ of 1.4 means roughly that in the population of incinerators about two-thirds will be found to have unit investments lying in a band from 29 percent less than the median line to 40 percent greater than the median line. Of plants chosen at random, the probability that the unit investment will be less than 71 percent of the median is equal to the probability that it will be greater than 140 percent of the median: this probability, incidentally, is about 16 percent. The lack of a statistical trend means that this probability does not change regardless of the size of the plant. This does not mean that a 100 ton per day incinerator on a proposed site will have the same unit investment as a 1,000 ton per day incinerator on the site. It may have a greater unit investment, but also it may have a lesser unit investment. However, out of all 100 ton per day incinerators, the most probable unit investment is $4300, and out of all 1,000 ton per day incinerators the most probably unit investment is $4300.

Remember that this unit investment is for plants without extensive air pollution control features. Addition of advanced features such as extensive air pollution control equipment, heat recovery, etc., result in a higher unit investment — possible appreciably higher. However, of the six plants in the sample having relatively simple air pollution control devices, mostly wet scrubbers, the statistical analysis did not reveal a significantly higher investment. Three of the six plants had investments higher than the median and three lower.

Also it should be explained that although the batch plants were both on the low side of the median and the rotary plants were on the high side of the median, the sample of these plants is not large enough to warrant a statistical conclusion that batch plants are cheap and rotary plants are expensive. A larger sample of these types of plants would be required to draw general conclusions about them.

Incinerator plants are not highly capital intensive. Measured in investment dollars per ton per year capability, the unit investment is about 12, well down in rank among chemical and process plants in general (examples: butadiene 1,500, sulfate pulp 310, soda ash 100, sulfuric acid 26). In a well-known listing of some 120 chemical processes, incinerators rank in the lowest ten percentile in unit investment.

As an example of some of the operating ratios, the actual man-hours per ton have been plotted against the average production and design man-hours per ton have been plotted against design capability to illustrate data for labor utilization in man-hours per ton. (Figure 2) The median labor utilization for plants producing 100 tons per day is about 1 man-hour per ton; for those producing 1,000 tons per day, about 0.44 man-hours per ton. For chemical process plants, in general, cost engineers have a correlation with size in terms of man-hours per ton per processing step. In these terms, incinerator labor utilizations are the same as the labor utilizations in other chemical processing plants measured per ton produced.

The total cost for the 23 incinerators in 1968 is illustrated in Figure 3. The cost at the actual utilization factor is plotted against average production (solid circles). The computed costs are shown when operated at a utilization factor of 1.0, i.e., operated at capability. This computation was made by adjusting the labor force to 168 hours per week and adjusting other items in a rational manner. For the cost at $\bar{U}$=1.0, there is no trend with capability and the median value is about $3.00 per ton. This means that if all the plants had been operated at full capability, the median cost would have been $3.00 per ton at 100 tons per day and also at a 1,000 tons per day. The entire trend of the cost at actual $\bar{U}$ against average production comes about because the $\bar{U}$'s of the small plants tend to be lower than those of the large plants; not only is there no scale economy in the unit in-

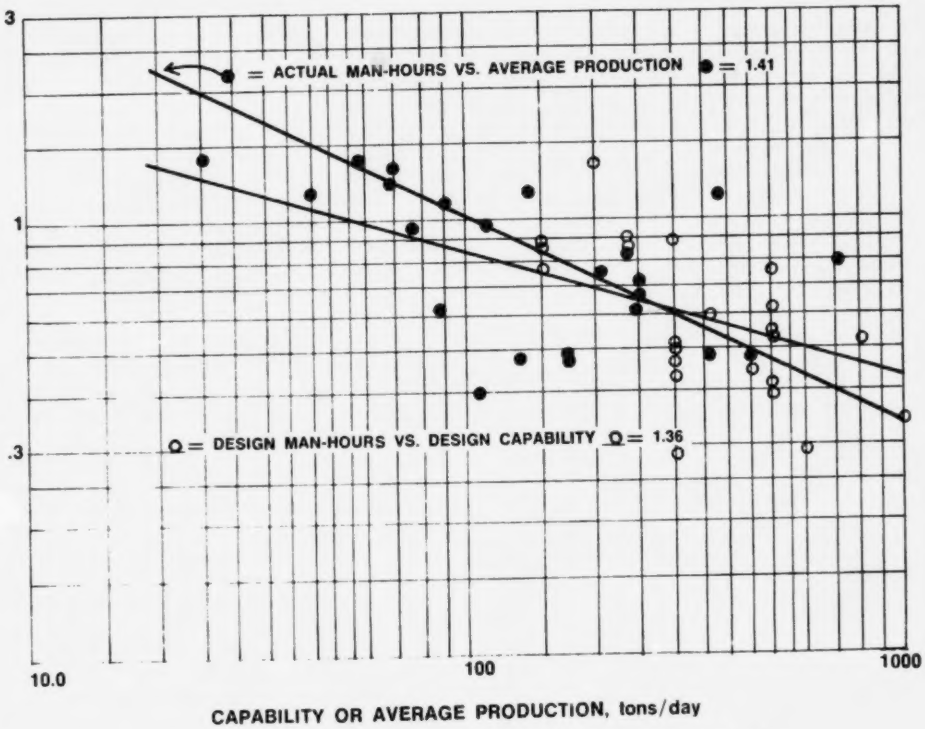

Figure 2: Labor Utilitization for 23 Incinerators in Actual or Design (Man Hours Per Ton)

vestment, but also there is no scale economy in total costs when plants are operated at full capability.

Since $\overline{U}$ is of such importance in the economic analysis, the actual magnitude is of interest. The chemical process industry as a whole operates day after day at an average $\overline{U}$ of 85 percent. In the study sample, the highest $\overline{U}$ was 80 percent, the lowest, 17 percent. From the regression line, the 1,000 ton per day capability plant may be expected to have a utilization factor of 61 percent; the 100 ton per day, 24 percent. To process 100 tons per day requires, in the median, a 270 ton per day plant that would operate at a $\overline{U}$ of about 36 percent; the unit cost would be about 82 percent above the unit cost if operated at full capability. To process 1,000 tons per day takes, in the median, a 1,500 ton per day plant that would operate at a 70 percent $\overline{U}$, with a unit cost 37 percent above the cost at full capability. In the whole sample, totaling 9,090 tons per day of capability, the average production was only 4,404 tons per day, an overall utilization of these facilities of 48.5 percent.

It is worthwhile to explore the causes responsible for these low $\overline{U}$'s, which may result from:

High Seasonality of Solid Waste Generation Rates

1. The seasonality of the generation rate was not studied in this survey but is proposed for later study. If, as an extreme example, all the solid waste were received during 6 months of the year and none during the other 6 months, then, dumping storage being limited to a week or so, clearly a $\overline{U}$ greater than 50 percent could not be achieved. The actual seasonality of generation rates is not believed to be great, however.

Not Achieving Rated Furnace Capability When Running

2. The data on some of the other factors contributing to $\overline{U}$ are given in Table 2. Not shown is the ratio of average tons per furnace hour to design tons per furnace hour. The median value was 1.10; the 90 percentile value, 1.47; the 10 percentile, 0.72. On the average the operators succeed in achieving, indeed exceeding, the rated furance capacity when running.

Furnace Out of Commission Because of Breakdown

TABLE 2
Factors Contributing to Utilization Factor

Capability, tons/day	*Pit capability, of burning capability*	*logistic ratios, logistic capability/nominal capability*	*Furance days intended/possible furnace days*	*Burning hours per day intended*	*Available furnace days (fd). fd intended and operable/fd intended*
800	57.84	1.000	0.854	-	-
500	18.31	0.895	0.714	11.46	0.885
500	18.31	0.895	0.714	12.06	0.805
500	35.39	0.996	0.714	-	0.500
200	6.41	0.658	0.854	5.82	0.994
300	18.07	0.893	0.900	-	-
360	15.31	0.877	0.793	11.92	0.490
150	19.23	0.900	0.770	3.85	-
300	25.76	0.939	0.810	14.50	0.940
500	18.19	0.894	0.740	-	-
500	47.53	1.000	0.712	18.64	0.977
600	19.48	0.902	1.000	16.71	0.979
150	14.11	0.870	0.854	11.00	0.962
1,000	23.44	0.925	0.854	18.35	-
240	14.83	0.873	0.712	8.89	0.946
150	28.37	0.955	0.854	-	0.974
240	16.85	0.884	0.712	20.60	0.465
300	40.64	1.000	0.854	17.24	0.977
300	40.64	1.000	0.712	6.22	0.907
450	22.25	0.918	0.783	16.97	0.652
300	29.65	0.962	0.712	20.30	0.865
300	17.54	0.890	0.954	10.76	1.000
450	6.21	0.822	0.854	-	0.942
Median	21.1	0.911	0.793	11.0 100 ton/day 23.0 1,000 ton/day	0.844

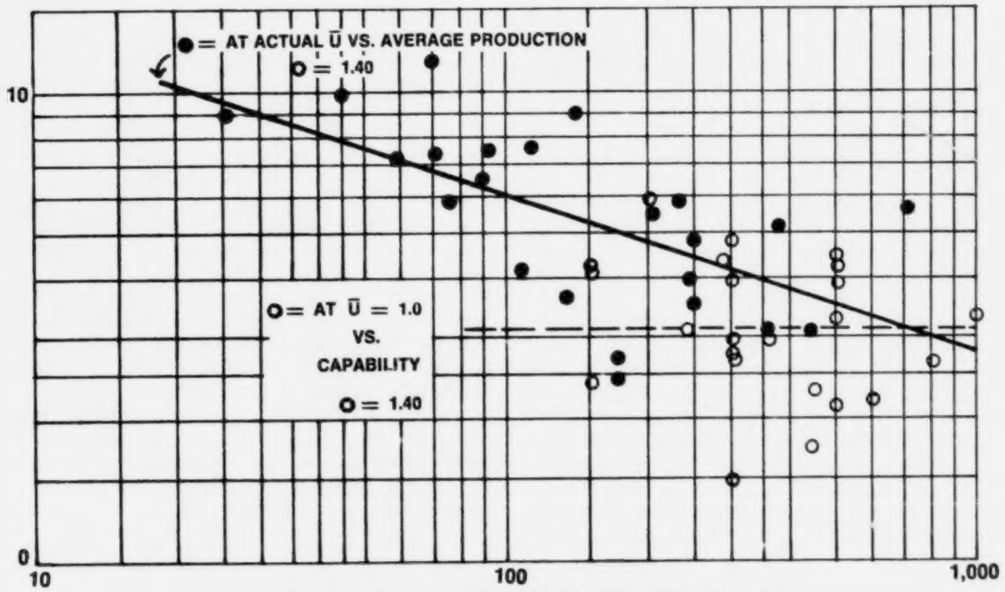

Figure 3: Total Cost of Incineration for 23 Incinerators

3. The "availability" column indicates the ratio of the number of days on which the furnace was intended to be operated and was actually operable to the number of days intended to be operated. One minus this ratio is the fraction of the days on which the operator wanted to operate but could not because the furnace was out of commission. The median availability is 84.4 percent; the 90 percentile, 100 percent; and the 10 percentile, 61 percent. Seven of the 23 plants had an availability greater than 95 percent; 11 of the 23 plants, greater than 90 percent.

Burning Stoppage Because of Delivery or Storage Logistical Defects

4. One common logistic defect in design is failure to provide pit capacity adequate for continuous burning. The "pit capability, hours of burning capability" column measures the number of hours that the furnaces could operate at full capability on the material contained in a full pit. In making this computation, some normalizing assumptions have been made, including that the intention is to receive waste 12 hours a day, 6 days a week, a typical receiving schedule. To achieve full burning capability 168 hours per week requires a pit capacity of 36 hours of burning capability. If the pit capacity, P, is zero to 12 hours, the hours per week at full burning capability is 6 (12+P); if the capacity is 12 to 36 hours, the hours per week at full burning capability is 132 +P; and if the pit capacity is greater than 36 hours, the hours per week at full burning capability is 168. The plant logistic capability in tons per week then is the product of these hours times the burning capability. The "logistic ratio" column shows the ratio of this logistic capability to the nominal capability of the plant. Only four of the sampled plants have a pit capacity great enough to allow continuous utilization of the full burning capability. There are really no very low values of the ratio: the lowest is 0.658, and all the others are above 0.8. The actual situation, however, is worse than the ideal situation computed. Some plants receive only 5 days a week or receive a reduced quantity on the sixth day, whereas the computation assumes that the average daily delivery will occur on each of the 6 days. With a 5-day receiving schedule, the pit capability has to be 60 hours to achieve full burning capability. This variable is not quantified in this analysis, however, because it is overshadowed by the two remaining variables.

Intention To Operate Less Than 365 Days a Year

5. In general, incinerator designers or incinertor management (it is not clear which is the cause and which is the result) do not intend to fully utilize the 365 days in each year and the 24 hours in each day to operate the furnaces. The "furnace days intended/possible furnace days" column shows the fraction of the 365 days per year on which it is intended to operate furnaces. Only one plant in the sample intended a 7-day-week operation. The ratio of 0.854 represents a 6-day-week; 0.712 indicates a 5-day week. The median is about 280 days per year out of the available 365.

Intention To Operate Less Than 24 Hours a Day

6. The "burning hours per day intended" column shows (approximately) the intended number of burning hours per day. This data actually showed a correlation with size; the median for plants producing 100 tons per day which was 11 hours, and for 1,000 tons per day which was 23 hours.

The median cost for maintenance, repair, and minor replacement was 40¢ per ton. Expressed as percent of investment the mean was 2 percent per year and the highest 3.2 percent per year. This occurred in five plants. The unit maintenance, repair, and minor replacement cost varied with plant age. The regression line values were 0.6 percent per year at 1 year of age and 2.1 percent per year at 10 years. This may be compared with typical experience in the chemical process industry where maintenance, repair, and minor replacement cost is now averaging something on the order of 4 percent per year.

There are two qualifications to this comparison. First, the maintenance, repair, and minor replacement costs are the least secure of those developed in the survey and tend to err by being low rather than by being high. Second, the final survey sample contained, for the most part, only plants that had been in actual operation and had generated cost data. Some of the candidate sample plants were eliminated because they had had such massive failures as to be virtually shut down. The fraction that these failures make of the total incineration population is not determined, but presumably if the failures had been included in the study sample, the maintenance, repair, and minor replacement costs for the entire sample including the substantial reconstruction measures would have been appreciably higher.

Comprehensive Industrial Solid Wastes Program at Dow Chemical

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Dow Chemical Company

This paper will discuss our solid wastes program at the Midland Division of the Dow Chemical Company. The emphasis will be primarily on the program; what it is, how it is implemented, the scope, the people, and some unit costs. Also, it will touch on problems that must be solved in the near future.

Basically, our program is to first concentrate on eliminating or reducing the solid wastes leaving the generating area and, secondly, to dispose of the remaining wastes in a manner that will not create immediate or long-term pollution problems.

Let us look at the first portion of this program a little closer. Basically, it is to introduce and put into practice the concept of defining the most economical alternate to achieve zero wastes leaving the battery limits of the process under consideration. This does not mean that processes must run at 100% efficiency, but rather than all wastes must be consumed or destroyed within the process. Although this is not practical to achieve in every case, it appears that if this attitude prevails, it is contagious and leads to a climate where enthusiasm and progress toward zero or reduced wastes becomes a portion of everyone's job.

This portion of the program is not readily achieved and must be continually used and maintained in order to keep it functional. Top management commitment-exercised straight across the board- is a very necessary basic requirement. Outstanding performance must be expected in research, process engineering, and production in order to achieve these goals. The second portion of our program is the disposal of solid wastes that are generated despite our best efforts to reduce them at the source.

Our primary incineration units used for disposal of solid wastes consist of a 65 $\overline{M}$ BTU/hour rotary kiln incinerator which is used for the incineration of chemical refuse and liquid residues and an 81 $\overline{M}$ BTU/hr. liquid residue incinerator. These units are backed up by one 32 $\overline{M}$ BTU/hr. Hooker liquid residue incinerator, a 56 $\overline{M}$ BTU/hr. Bigelow Liptak liquid residue incinerator, and a 65 $\overline{M}$ BTU/hr. vertical liquid residue incinerator. All water wastes resulting from these operations are routed to our wastewater treatment facilities. In addition to these facilities, we also operate a landfill area which covers 200 acres.

Currently, we are receiving by dempster about 650,000 gals./mo. of liquid residues, 500 55-gal. drums/mo. which contain miscellaneous liquid residues, and 20,000 yd.^{3}/mo. of refuse for disposal. The liquid residues are by-products, contaminated chemicals, or bad batches that cannot be economically reclaimed, or reused. These materials, which vary from light solvents to very heavy still residues, must be disposed of without causing safety, air, or water pollution problems. The majority of these residues are solids at room temperature and, therefore, must be kept hot in order to remain liquified. Many residues are chlorinated and can contain as high as 50% chlorine, plus several percent of ash in the form of Fe, Ca, Mg, Na, oxides, and chlorides. Refuse consists of plastic sheets, trimmings, strands, powders, styrofoam, paper, boxes, wood, and other solids of high BTU content, plus many non-burnable solids such as cinders, demolition, dirt, and sludges.

Another form of solid wastes is that generated by our laboratories. Most of these waste products are extremely hazardous. Toxic, reactive, or explosive, these items, although small in volume, frequently present the most difficult disposal problems. To bring in additional expertise, we consult with a reactive chemicals committee whenever a potentially hazardous disposal problem comes up. A key part of our philosophy and procedures is to have the individual that created the problem play a significant part in determining the disposal steps to be used, and in the disposal operation itself. Using this procedure, we never have had an incident. Also, and not so surprisingly, we rarely had the same individual create a problem the second time.

All requests for hauling wastes are phoned to the incinerator office. Any request not contained in our files in apparently not routine and turned over to supervision for investigation. All information necessary to backcharge the cost of disposing of this waste to the account of the generating source is entered on an IBM card. All information for pickup is radioed to a truck in the area. Pickup service is available 24 hours/day, seven days a week, although the bulk of the pickups take place on the day shift, Monday through Friday. Recharge costs for hauling refuse run in the vicinity of \$.60/yd.^{3}, either to the burner or to landfill. Recharge costs for hauling liquid wastes in dempster quantities are about \$.01/gal.

The liquid waste materials brought to the incinerator in dempster tanks are transferred to predesignated receiving tanks which contain compatible wastes. All drums of liquid wastes are also transferred to the receiving tank by way of a drum dumping dock. The waste is strained as it is pumped from the receiving tank into a burning tank, where it is blended for optimum burning characteristics. All liquid residues are burned in suspension by atomization with steam or air. Drum quantities of solid tars are destroyed by feeding them into the rotary kiln incinerator via a hydraulically operated drum and pak feeding mechanism. All refuse, except full drums and paks of material, is dumped into the refuse pit. An overhead crane is used to mix the refuse and elevate it to the changing hopper of the rotary kiln.

While refuse is being fed, liquid tars are fired horizontally into the rotary kiln. As the refuse moves down the kiln, the organic matter is destroyed, leaving an inorganic ash. This ash is made up primarily of slag, plus other non-burnables such as drums and metal. The ash discharges from the end of the kiln into a conveyor trough that contains three feet of water. After quenching, the material is conveyed into a dumping trailer and landfilled.

Upon leaving the kiln, the products of combustion enter the secondary combustion chamber and impinge on refractory surfaces that cause a swirling action. No secondary fuel or afterburners are used. Downstream of the secondary combustion chamber, the gases pass through several banks of water sprays in the spray chamber, in which the flyash is knocked down and sluiced onto the ash conveyor floor. The cooled gases pass under a stack damper, and to a 200-foot tall stack.

Our rotary kiln does not have the capacity to burn all of our liquid residues. Also, we burn residues which have a very low ash content in our kiln, and route the remainder to the 81 $\overline{M}$ BTU/hr. liquid residue incinerator. Our liquid residue incinerator has a combustion chamber 35 feet long and 10 feet square in cross section. Residues are fed into the unit through a combination of four dual fired nozzles. The combustion gases are quenched in a spray chamber, which is followed by a high pressure drop venturi scrubber and a demister-cooler. About 3,000 gpm of water is recycled from the primary tanks of our wastewater treatment facilities to furnish scrubbing water. The scrubbing water flows back to the wastewater treatment plant for treatment. This is a part of our continual program to reuse water. About 1,100 connected horsepower is required for this unit.

The standby units must be kept ready for operation in the event of failure of one of the primary units. As you can imagine, it is no easy task to start up a unit that has not been operated for several months. This brings up another point. Our entire solid and liquid waste operations are maintained by a field service crew, which include a full-time electrician, machinist, pipe fitters, and a boiler maker, among other trades. This crew is further backed up by instrument men, masons, millwrights, and others that are located in our central shops. The expertise, knowhow, and dedication that these people always show when a unit is down is tremendous. They are a vital part of our operation, and therefore, of our program. A good deal of supporting equipment is needed for these units. Utilities and utility distribution systems for electrical power, gas, water, steam, nitrogen, and air are required. Storage space for refractories and other special equipment is a must, since items such as refractory materials can take up to nine months per delivery. Wastewater treatment facilities for treating scrubber discharges are necessary considerations, and provide a key factor in fail safe operation.

In terms of today's dollars, we have well over six million dollars invested in incineration equipment alone at our Midland Plant. In our landfill operations, we landfill about 20,000 cu. yd. of material monthly. A variety of materials enter our fill, such as rubble and demolition, primary sludge, incinerator ash, certain scrap metal, and special nonburnable solids. For example, attempting to landfill about 200 cu. yd./day of primary sludge is a challenging job, and requires the best in experience and equipment. These materials are mixed and covered with sand to form a stable fill. We are using a bulldozer full time, plus a crane and truck part time. We are fortunate in that we have relatively substantial quantities of sand available in our fill area, plus haulings of rubble and demolition. Our recharge costs for this particular site run about $1.50/cu. yd.

One of the concepts we try to get across to the plant people concerning our landfill operations is that we are operating a landfill, and not a junk yard. We do not accept contaminated chemical processing equipment; we insist that it first be decontaminated. When that step is complete, we find that in many cases the equipment can be sold for scrap or salvage. Size of material going to our fill is also regulated. This eliminates deposition of large fill items in our landfill operating area, which could be extremely heavy and difficult to handle and take up a large volume of fill. Our landfill area is continuously monitored by remote television during the daylight hours, and regularly patrolled at night, since we are concerned that this landfill, as with all landfills, could provide an attractive nuisance. Finally, we conduct several practice fire drills each year in order to review and test established procedures with our fire, service, and plant protection departments.

Defensive research plays a vital role in our total efforts. For our incineration units, we strive to completely define what is happening in the system under certain specific conditions of operation by actual field tests and measurements. With this knowledge, we can confidently select the optimum operating conditions for disposal of a variety of materials that have widely diversified properties. Another area of concern is materials of construction, as it is in any incineration operation. Accurate operating and maintenance records are vital to evaluating various materials of construction. The selection and incorporation of reliable instruments and controls also play a significant part in our total efforts. In some cases, we find it advantageous to build up a relationship, based on trust and respect, with equipment vendors who specialize in specific equipment areas. This type of relationship usually works to the benefit of both parties.

Also, we work pretty hard at forming and maintaining attitudes at an optimum level. This includes training, preparing meaningful operating instructions, and reviewing these instructions in depth. We also spend quite a bit of time just listening. We insist on strict adherence to established safety standards concerning raw waste materials coming to us. If the standards are not met, we refuse to accept the waste and return it back to the customer. Specifically, we are referring to standards regarding container types, labeling, and tagging, not to mention other standard practices we use in specialized cases.

Another area of concern is to make certain that our equipment meets current FIA standards, not only on the drawing board, but consistently in the field under actual operating conditions. All of our shutdown and safety systems are tested at scheduled time periods, following written test procedures. In order to operate a unit safely on waste materials, which have a wide range of physical and chemical properties, the utmost of ingenuity and plain hard work is involved in the design and maintenance of the control system.

Finally in the safety area, there is the factor of environmental health in the waste processing area. We have frequent consultations with our environmental and medical people who investigate and monitor health problems ranging from noise control to performing routine clinical tests which check key bodily functions.

One of the problems we are working on today is the disposal of sludges in various quantities, for example, inorganic salts that may be saturated with solvent, or just plain organic process sludge. This material must be hauled through the plant, emptied into storage or feeder equipment, and then introduced into a destructor unit of some type, and completely destroyed down to inorganic ash. These operations are difficult for us to perform with our present equipment, and must be developed and refined.

Another area of concern is the disposal of brominated liquid tars and sludges. The problem is the evolution of significant quantities of free bromine when ordinary combustion procedures are used. Again, it appears that recovery of the relatively valuable bromine is the answer, rather than complete disposal.

A third area we are watching carefully is that of residue quality. As more fuel quality wastes are being utilized within the waste generating processes, wastes of low BTU value, high ignition temperature, poor handling, and burning characteristics start to have a sizeable effect on our overall residue mix. In order to destroy this residue mix safely and efficiently, operating procedures must be modified, and in some cases, additional processing equipment must be installed.

This is a brief outline of today's solid waste program at our plant. We have shown that a disposal program for solid wastes in a chemical complex involves much more than the construction and operation of incineration or landfill facilities. It involves first and foremost management — as the title of this conference so aptly indicates. Management in formulating and carrying out a program, a program that involves problem definition, priorities, safety, quality, productivity, reliability, public relations, research, legal questions, monitoring, economics, and many other areas. The program must be a growing and flexible program and will require careful attention to short and long range objectives.

Integrated Industrial Solid Wastes Processing Facility of COPE-Houston

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COPE, Inc.

A sub-title of this paper could be OPTIMUM WASTE DISPOSAL FOR THE PROCESS INDUSTRIES. The term "Process Industries" has particular reference to the refining, petrochemical, and chemical industries, as they traditionally produce a substantial amount of by-products and waste, which must be further processed or disposed of.

The process industries have had a tendency in the past to concentrate themselves in various locations around the country primarily to take advantage of product exchanges, market concentrations, raw material supplies, favorable labor markets, and low cost utility availability. This tendency seems to be changing recently, with the advent of pollution control. A company considering a new processing facility must now focus serious attention on the pollution problems. Many of the areas of high industrial concentration have older plants which were not designed with pollution control in mind. Consequently, the aqueous wastes may be taxing the surrounding rivers' and streams' ability to carry them away, available land for sanitary landfill of solid wastes may be scarce, and the airspace may already be overloaded with chemicals and particulate matter. Thus, all of the advantages of locating in an area of industrial concentration may be overbalanced by pollution control considerations, and a new plant will be built in a remote area where attention to pollution control is not as serious.

There is, apparently, quite a range in the degree of pollution control being exerted by the state and local authorities in various parts of the country. However, nearly all operating plants have had to "come to grips" with their waste problems. The prospect of having to meet newly established pollution standards is frequently quite a shock to the operating companies, particularly the ones with older plants. Since a control program can impose a very heavy financial burden on an older plant, the company must do everything possible to optimize their pollution control.

It might be interesting to trace through the various steps which the operating companies normally follow in arriving at the "hour of decision" on their pollution control program. The first step is normally data gathering. Some companies have no idea of the quantity and quality of their wastes until they are called upon to control them. They must begin measuring, weighing, accumulating, segregating, sampling, and analyzing for several months to get meaningful data. Once this data is analyzed, the wastes are usually categorized.

Categories or Types of Industrial Wastes

Gaseous emissions
Biological aqueous wastes
Corrosive or toxic aqueous wastes
Liquid hydrocarbon wastes
Semi-solid wastes
Solid materials

A. Typical examples of gaseous emissions are exhaust gases from various process furnaces or reactors and waste incinerators.

B. Biological wastes are those which can be readily converted by biological activity into other non-toxic materials.

C. A good example of corrosive or toxic aqueous wastes would be caustic or acid solutions.

D. Liquid hydrocarbon wastes are common by-products of both refining and petrochemical plants.

E. A typical example of semi-solid wastes is filter aid material with a high water content.

F. Solid materials can be anything from plastic scraps to form lumber.

The development of this type of information is expensive and time consuming but is a very important first step towards arriving at a solution of the pollution problems. Once the basic data is available, the plant engineers can begin making process studies and adjusting the process variables in an attempt to eliminate or reduce the various wastes. This phase can take several months to develop meaningful conclusions. It is frequently found that the plant can be adjusted to reduce one waste at the expense of increasing another. Therefore, the overall problem must always be kept in mind.

After the study program is completed and it is concluded that disposal measures are necessary, the operating company must decide what approach is to be employed to solve their pollution problems. The waste can be eliminated from the environment using "ultimate" disposal methods, disposed of by using other disposal methods, or stored in landfill. The following table lists the methods which fall into these categories.

Ultimate Disposal Methods	*Other Disposal Methods*
High temperature incineration	Dispersal to atmosphere or water
Biological oxidation	Landfill
	Ocean dumpings
	Deep well disposal

While there are no true ultimate disposal methods, incinceration and biological oxidation are more generally recognized as altering wastes to a form which is no longer a likely pollutant. Incineration normally converts wastes to carbon dioxide, water vapor, sometimes sulfur dioxide or halogens, and particulate matter. A well designed incineration facility will remove both the chemicals and solids from the stack gases, leaving a pollution-free gas and useful by-products if their purification is economically justified. The other methods listed here are often employed as their cost is usually less, but there is some question about the longevity of some of these methods with pollution control standards being tightened.

A very interesting disposal technique which is sometimes used is deep well disposal for toxic and corrosive materials. This method requires careful control and surveillance but affords the advantage that wastes stored in this manner may be withdrawn in the future if they should become useful raw materials.

Having determined the type and quantity of waste a given operating company produces and the best method of disposal, the company must decide upon one of two basic alternatives — either install "in-plant" facilities or contract with a disposal service. There are, of course, advantages to an "in-plant" facility, such as having the disposal facilities designed for a specific mixture of wastes and allowing the operating company complete control of the disposal. The disadvantages are mainly economic as illustrated by Figure 1.

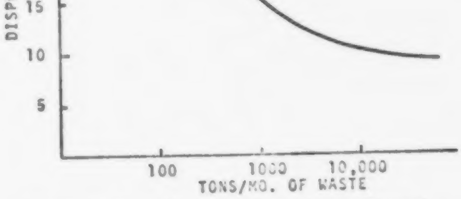

Figure 1: Approximate Unit Costs of Waste Disposal

It is apparent that waste disposal costs increase very rapidly as the size of the disposal facility is reduced. Most "in-plant" units are extremely small compared to a large-sized central waste disposal plant which offers disposal service. Another disadvantage to "in-plant" disposal is that plant management and the technical staff are usually pre-occupied with plant operations and do not have time for disposal problems. A central waste disposal facility which offers industrial disposal service benefits industry in many ways, as illustrated by Table 1.

TABLE I
Advantages of Central Industrial
Waste Disposal Facility

1. Economy of scale
2. Lower total cost
3. Zero capital investment by operating companies
4. Facility is not occupying operating companies' property
5. No reports, sampling, or inspections
6. No meteorological forecasting
7. Hazard and nuisance free
8. Wastes can be blended beneficially
9. Technical control
10. Full-time specialists
11. Continuous operation
12. All weather conditions
13. Assurance of a future means of disposal at lower cost regardless of changes in law
14. Expansion and additions at low unit cost
15. Management free
16. Favorable community image
17. No project or start-up problems

The central waste disposal concept is consistent with the stated policy of the State of Texas "to encourage and promote the development and use of regional and area-wide waste collection, treatment, and disposal systems to serve the waste disposal needs of the citizens of the State." (Regulations of the Texas Water Quality Control Board [which has jurisdiction over industrial waste] Chapter III, Section 300, Rule 300.1b, Section 1.)

It is interesting to consider the total economic savings to the industrial community if a central facility is available. Such a facility as COPE is planning for the Houston industry and other areas would have an ultimate capacity of 15,000 tons per month and a capital investment of some $5,000,000. The only available alternative to industry would be for each plant to install small in-plant facilities normally ranging in capacity from 50 to 1,000 tons per month. The aggregate investment in these facilities could total some $7,000,000.

Comparing the yearly operating costs for these two alternatives: The central facility would cost approximately $2,250,000 while the total individual operating costs could be as high as $4,000,000 per year. Thus, the availability of a central facility affords a significant cost saving to the industrial community as a whole. A long-range benefit derived from the central disposal facility is that some plants are installed in an area primarily because the economics are improved by the availability of waste disposal service. As the industrial development is accelerated, the existing companies can benefit from complimentary manufacture, product exchange, etc. from the new facilities.

COPE developed the concept of a centralized waste disposal facility to meet the needs of the Houston industry and other areas of concentrated industrial activity based on a careful study of industry's needs in the field of waste disposal, and concluded that a plant based on high temperature oxidation processes is best suited for the process industry's needs. The project criteria which has been used in the development program is as follows:

(1) The plant must be designed to meet the most rigorous foreseeable emission standards when processing various types of industrial wastes.

(2) There must be rigorous operating controls to prevent hazardous or nuisance emissions.

(3) Operating costs should be less than alternative methods of permanent waste disposal on a plant-by-plant basis.

(4) Capital requirements should be less than the aggregate which would be required for individual facilities.

(5) Facilities should be so located that transportation charges from users' plants are at a minimum.

(6) The central plant should be a show place for good industry image.

(7) And, importantly, the plant should be as reliable as the process industry it serves.

Based on these "ground rules," Foster Wheeler Corporation was selected to conduct engineering studies. These studies have evolved into a plant concept for disposal of the categories of wastes suitable for disposal by combustion techniques. These wastes fall into the general categories of liquids, semi-solids, and solids (Table 2).

The liquids to be processed include tank bottoms, tank cleanings, oil and chemical sludges, tars and asphalts, aluminum alkyls, polymer residues, carbon tetrachloride, isocyanate residues, organic alcohols, methanol solutions, PVC wastes, and soot slurry. The semi-solids to be processed include soot cake, filter cake, filter aids, spent clay, and sediments. The solids include trash, polymer scrap, rubber scrap, and various types of paper scrap.

The central plant has been designed to require approximately 200-foot frontage on a navigable

TABLE 2

Typical Industrial Waste Materials Available for Centralized Disposal in the Houston Area

Liquids	*Semi-Solids*	*Solids*
Tank Bottoms	Soot Cake	Trash
Tank Cleanings	Filter Cake	Polymer Scrap
Oil and Chemical Sludges	Filter Aid	Rubber Scrap
Tar and Asphalts	Spent Clay	Paper Scrap and Waste
Aluminum Alkyls	Sediments	
Polymer Residues		
Carbon Tetrachloride Residue		
Isocyanate Residue		
Organic Alcohols		
Methanol Tails		
PVC Wastes		
Soot Slurry		

stream to allow deliveries of wastes by barge. The site will also be equipped to handle trucks and rail cars which can be unloaded into intermediate storage without affecting the composite wastes being charged to individual disposal units at the time of delivery. The actual incinceration will be accomplished by three separate process "trains" which handle the wastes in the groupings just described.

Liquids

The liquids will be incinerated in an adiabatic "liquid furnace" along with certain slurries with high BTU content. The heat balance will be controlled by blending of wastes and by adding supplementary fuel if necessary to maintain a minimum of 1800°F. The furnace, either vertical or horizontal, will be equipped with a series of burners, each designed for a different feed specification. This system affords the maximum flexibility possible to accommodate whatever changes develop in the instantaneous and long-range feed composition.

Semi-Solids

The semi-solids, containing a high percentage of ash or inorganic non-combustible material, will be incinerated in either a Multiple Hearth or Rotary Hearth Furnace. This equipment can burn very high moisture content solids and slurries through the employment of rabbles or plows which turn over the waste to expose fresh surface for combustion. Either the rabbles rotate or the hearth rotates depending on the selection between the Multiple or Rotary Hearth equipment. High water content filter aids can be handled very effectively with this equipment which gradually dries the material through surface combustion supported by counter-current air and gradual temperature increase until all the combustibles are oxidized.

Solids

The solids will be incinerated in a Rotary Kiln, the most versatile of the three process units. This unit has the capability of combusting practically any type of waste, but will be used primarily to incinerate polymers, rubber scraps, and other solids. Many of these materials present a unique problem because they become fluid at combustion temperatures. The kiln spreads these materials out over its internal surface and, through careful blending of less volatile wastes, controls the combustion at the desired level.

The rotary kiln requires an elaborate feeding system in order to handle a range of waste size and type. The kiln design will be capable of handling 55 gallon steel drums of toxic volatile materials in a safe manner.

The kiln will be able to utilize supplementary fuel to control the combustion temperature at the desired level — 1600 to 1800°F. This supplementary fuel can either be natural gas or high BTU content liquid waste. As shown schematically, the combustion gases from the three incinerators are then combined and taken into a Secondary Combustion Furnace in order to complete the oxidation decomposition of potential or actual gas pollutants and unburned material from the Multiple or Rotary Hearth Furnace. The 1800°F effluent from the Secondary Combustion Chamber may either be quench cooled with water sprays or passed into a waste heat recovery boiler to reduce the temperature to about 700°F, at which temperature it can be purified by wet scrubbing. The beneficial use or sale of steam will govern which alternative is employed in each installation. Next, the combustion gases must be purified to remove both particulate matter and undesirable chemicals such as hydrogenchloride or sulfur dioxides. After extensive study, COPE has decided to employ a wet scrubbing system for gas purification. The system consists of first contacting the gases from the quench cooler or waste heat boiler with a spray of water in order to reduce the temperature to 150°F. The cooled gases are then scrubbed in a venturi scrubber where practically all particulate matter, halogens, and a large percentage of sulfur compounds are removed by the circulating solution. These latter materials can be recovered as salable products if economically feasible. The then clean gases containing essentially CO_2, water vapor, and excess air are introduced to the bottom of a 250-foot stack where they are reheated with clean fuel and discharged to the atmosphere.

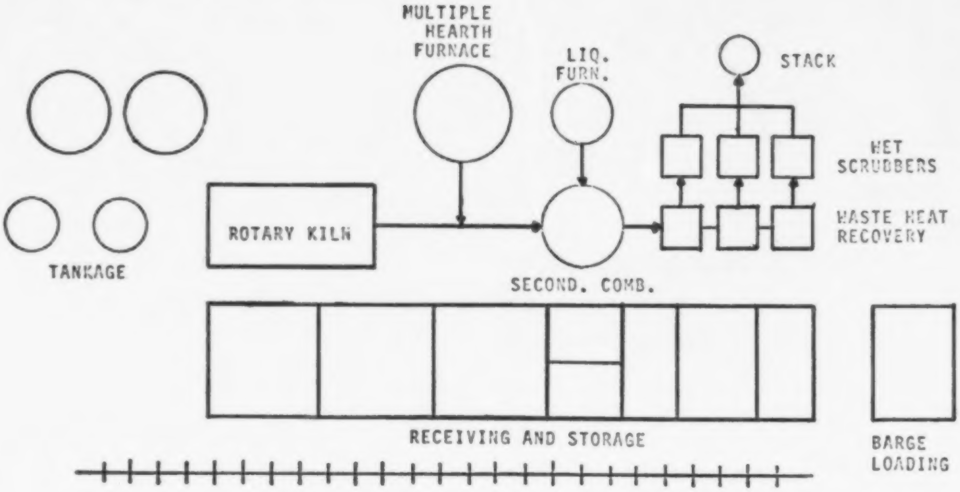

Figure 2: Simplified Flow Diagram of the COPE-Houston Facility

The current Texas Air Control Board regulations allow a facility such as proposed by COPE to discharge 650 lbs. per hour of particulate matter and 5,200 lbs. per hour of sulfur dioxide in the stack gas. COPE has designed its facility to discharge only fractions of these values in order to offer assurance to industry that it will meet the pollution standards under any conditions now and in the future.

Incineration, the disposal technique for this installation, is recognized to be one of the few long-term ultimate solutions for many industrial waste problems. COPE, through its approach to phasing processes as they are needed, can offer its waste disposal service in the range of $8-$12 per ton of waste, depending upon the BTU content, ash and non-combustible content, and degree of difficulty of storing and handling. In many cases this will be the only economic solution available to the process industry for waste disposal problems.

Having an industrial waste disposal service with an established disposal fee enables each processing plant to determine the optimum disposal method for its operation. We believe that our program for installing central waste disposal facilities in various parts of the country will have a significant effect on the control of pollution from the process industries.

The Production of Charcoal from Bagasse

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Physical and Chemical Characteristics of Bagasse

Bagasse is a solid waste which results from the extraction of sugar from sugar cane. Sugar is present within the cane stalk as cane juice and is extracted by passing the cane through heavy rollers and shredders to press the liquid fraction from the solid residue. As the fiber passes through each roller to the next, it is sprinkled with hot water to dilute the remaining juice and permit its extraction.

Fibrous material discharged from sugar mills after sugar extraction is called *bagasse*. The bagasse is usually low in sugar, indicating high extraction efficiency. The composition of bagasse is not constant and is dependent upon both the cane and the method of extraction. Wet bagasse is usually 40 to 50 percent water and 50 to 60 percent solids. A typical analysis[1] of wet bagasse discharged from the mill shredders and rollers is shown in Table 1. The moisture content of Hawaiian Bagasse is somewhat less than 48 percent because of good mill efficiency, averaging about 44 percent.

Bagasse is physically constituted of two fractions, pith and fiber. Pith often contains more than 25 percent pentosans on a dry weight basis. The fibrous fraction is higher in cellulose and with fibers approximately the same length as hardwood. Bagasse fibers are higher in ash, hemicellulose, and pentosans than wood. They have a lower lignin and alphacellulose content[2]. In general, the chemical characteristics of bagasse are more similar to hard than to soft wood.

TABLE 1
Analysis of Bagasse

Wet Bagasse Discharged from Mill Rollers[2]		*Dry Fiber*		*Ultimate Analysis Dry Bagasse*[3]	
Water	48.5%	Cellulose -	50-60%	Carbon -	43-47%
Fiber	46.5	Pentosans-	20-25	Hydrogen-	5.4-6.6
Sugar	4.0	Lignin -	10-18	Oxygen -	45-49
Ash	1.0	Ash -	15-30	Ash -	1.5-3.0
Total	100				

Several potential commercial uses for bagasse require separation of the fiber and pith. The Rietz Disintegrator (patented by the Hawaii Sugar Planters' Association) has been successfully used for wet depithing[2]. When separated from pith, fiber has been used for the manufacture of paper, corrugated boards, newsprint, hardboard, insulating board, and lightweight concrete. Pith has been used for animal feed and as a source material for furfural and charcoal. Charcoal and furfural can also be produced from the unseparated bagasse.

Bagasse is commonly utilized as fuel for the operation of sugar mills. The heat value of dry bagasse is about 7800 to 8300 BTU per pound[3] and, with 44 percent moisture, the net heat content has been reported to be 3000 to 3300 BTU per pound. Wet bagasse, as normally fed to mill boilers, has a heat value per ton equal to 1.0 to 1.2 barrels of oil. Sugar mills in less developed regions of the world are often inefficient in the use of bagasse and additional fuel is sometimes required as supplement. For modern mills, bagasse production may be larger than the in-plant fuel requirements and surplus bagasse sometimes results.

In Hawaii, 4740 pounds of wet bagasse and 6940 pounds of wet "trash" result for each ton of sugar produced. With an approximate 1.2 million ton per year sugar production, some 2.8 million tons of wet bagasse (1.5 million tons dry) and 4.2 million tons of wet trash (2.1 million tons dry) are produced within the state each year.

For maximum plant efficiency, wet bagasse is usually fed directly to the mill boilers as it is discharged from the plant rollers. A substantial increase in heat value can result from air drying previous to discharge to the boilers, but it has not been economical to provide equipment and facilities for drying. Mill boilers are almost always designed for burning bagasse with 40 to 50 percent moisture content.

The present use of bagasse as a fuel appears to be a satisfactory disposal method for Oahu; no large excesses of bagasse are now available for other purposes. This production-use balance could change with increased sugar production and with improved boiler efficiencies. In terms of fuel oil of equal heat value, wet bagasse now has a value of $8 to $10 per wet ton. For some mills of the state, however, excess bagasse does result and its disposal has been a problem. For these mills, the excess bagasse has no value and the cost of disposal causes it to be a liability. In existing areas of surplus, bagasse disposal of this solid waste has become a problem.

If economic commercial uses can be discovered, for example the use of bagasse for charcoal, an ample supply of excess bagasse is available for initial markets.

Manufacture of Charcoal From Bagasse

Charcoal is manufactured by carbonizing (destructively distilling) wood to charcoal chunks or by destructive distillation of sawdust or agricultural products. Chunk charcoal can be used for fuel directly as discharged from the carbonizing retort, is often less expensive than charcoal briquettes, and, for some types of cooking, is considered preferable. Carbonized sawdust or agricultural products must be mixed with binder, pressed, and dried into briquettes after distillation.

The value of charcoal as a fuel is related to its cleanliness, heat output, ease of ignition, time of burning, and taste imparted to foods. Some restaurants believe chunk charcoal to be more desirable for cooking because of improved flavor to the food, less smoke, lower cost, and low burning temperature. This last, low burning temperature is sometimes considered a desirable characteristic for charcoal used in cooking.

Most commercial charcoal is now in the form of briquettes rather than chunks because briquettes are cleaner, burn longer, and are easy to handle and package. Good quality charcoal briquettes can be readily ignited, burn with a minimum of smoke, and are dense and hard. Charcoal briquettes now represent almost the total retail market, and the use of charcoal chunks is largely restricted to specialty restaurants.

Commercial Production of Charcoal

The annual production of charcoal in the United States is somewhat over 500,000 tons per year. Charcoal is used as a fuel, in the chemical industry for the manufacture of paint (pigment), rubber, pharmaceuticals, fireworks, brake linings, calcium carbide, and other products; for the manufacture of activated carbon and for such miscellaneous purposes as nursery mulches, manufacture of crayons, and in poultry and stock feeds.

Destructive distillation of wood or vegetable materials results in the production of charcoal, gas, and distillate. The gas is constituted of 50-60% CO_2, 28-33% CO, 3.5-18% CH_4, and 1-3% H_2. Heat value of the gas is about 300 BTU per cubic foot[4].

The distillate is constituted of water, pyroligneous acid, and tars:

Pyroligneous Acid

This fraction contains some 30 or more compounds including acetic acid, methanol, and acetone. On a dry weight basis, the yield for hardwoods is approximately (percentage in terms of dry wood weight):

Acetic Acid	4.0-4.5%
Methanol	1.0-2.0
Acetone	0.0-0.5

Tars (Two types)

1. Soluble in pyroligneous acid and which can be separated only by refining.

2. Settled tars which are insoluble in pyroligneous acid.

Settled tars can be separated into (a) light oils with boiling point as high as 200°C and containing aldehydes, ketones, acids, and esters; (b) heavy oils with boiling point over 200°C and with phenolic components; and (c) pitch.

For hardwood, the tar yield is between 5 and 12 percent. The light oils are useful solvents, the heavy oils contain cresols and are useful as wood preservatives and disinfectants, and the pitch is useful for waterproofing.

The charcoal yield for both hard and soft woods is about one-third of the initial raw material. Destructive distillation or carbonization in the absence of oxygen is usually at temperatures of 400 to 500°C.

For hardwood, distillation at 400°C results in charcoal yields of 37 to 40%, at 500°C the yield may be about 31%, at 600°C, about 29%, and at 1000°C, about 27%. Soft woods produce about one-half as much methanol and about one-fourth as much acetic acid as hard woods; soft woods, however, also produce turpentine, pine oil, and rosin oil, which are valuable.

Review of the Literature on Charcoal Production from Bagasse

Previous to initiation of research, a literature survey was conducted to review previous work which might be of value. The production and manufacture of charcoal is well documented; for bagasse, however, only two useful reports were discovered: (a) a paper on destructive distillation of bagasse by Othmer and Fernstrom[5], and (b) EPCA Report No. 13 by the Hawaii Economic Planning and Coordination Authority[6] which related to the manufacture of charcoal from bagasse pitch.

For many years, the Othmer and Fernstrom report has been classic in its discussion on the manufacture of charcoal from bagasse. That work, undertaken at Brooklyn Polytechnic Institute almost 25 years ago is still a useful survey and report on the use of bagasse for production of charcoal briquettes.

Othmer and Fernstrom found that the destructive distillation of bagasse resulted in five useful products - acetic acid, methanol, combustible gas, tar, and charcoal. On a dry weight basis, percent yield for each of these products was:

Product	*Percent Yield*
Charcoal	28.5 - 52.3
Gas (By difference)	26.5 - 53.4
Tar	4.1 - 7.4
Acetic Acid	1.5 - 2.0
Methanol	1.5 - 2.0

The EPCA Staff Report No. 13[6] was a literature survey on charcoal production together with an economic study to evaluate charcoal briquette manufacture from bagasse. Because of changes in the economic picture the report has lost much of its value.

Charcoal Research for this Project

This research on charcoal production from bagasse has included:

1. Studies on charcoal yields from bagasse and techniques for destructive distillation. Gas production from the distillation process has been carefully measured and the gases resulting from distillation have been identified to establish potential heat value. Distillate production has also been measured.
2. The development of briquetting techniques for the production of useful commercial charcoal briquettes from bagasse charcoal. Briquetting has been a particularly troublesome problem and has required more attention than any other part of the charcoal study.
3. Devising method for coating briquettes for the production of clean, easily ignited charcoal briquettes. This procedure may be of commercial value since it overcomes two objectionable characteristics of conventional charcoal briquettes: tendency to soil hands and difficulty of ignition.

Research on Destructive Distillation of Bagasse

For the studies reported here, charcoal was produced in a Model F-A1635 Thermolyne 6" × 6" × 14" throat 0-1200°C furnace with temperature control. Charcoal was produced by two methods: (1) in a specially constructed pipe retort which could be used for materials-balance studies and for gas analysis and (2) by use of 300 ml beakers for determining the feasibility of charcoal production without special airtight containers.

Tests using the pipe reaction vessel were conducted at between 325 and 600°C. Each experiment required weighing a 25 or 50 gram portion of dry bagasse which was then charged into the reaction vessel. The pipe reactor was placed in the furnace, which had been previously heated to the desired temperature. Gas production was noted within 3 minutes. The gas was passed through two traps to capture tar and liquid, then collected over brine solution. After approximately 15 minutes, gas production ceased and destructive distillation was complete. The charcoal and liquid fractions were weighed, and the gas weight was estimated from the volume captured and analysis of the gas by gas chromatography.

Charcoal yield when using the pipe retort varied from a maximum 39% at 325°C distillation temperature to a minimum 28.8% at 600°C. Yields between 425 and 600°C were almost uniformly 29%. Percent tar plus distillate was 20 to 38% with 36% average. Gas production was 6 to 10 liters for 100 grams dry initial bagasse; experiments conducted at temperatures between 420 and 600°C usually resulted in about 10 liters gas yield per 100 grams.

Analysis of the gas showed it to be constituted of approximately 50% carbon dioxide (CO_2), 27% carbon monoxide (CO), 18% methane (CH_4), 2% hydrogen, and 3% unidentified hydrocarbons. The heat value was computed to be about 300 BTU per cubic foot of gas.

With open 300 ml. containers, no attempt was made to collect the gas, and percent charcoal yield only was determined. This yield varied from 24.4% charcoal at 600°C to 31% at 400°C. Destructive distillation at 400°C or higher was complete after 14 to 20 minutes. Distillation at lower temperatures was attempted but the resulting material was brown in color rather than black and not considered to be completely distilled after 30 minutes.

Formation of Briquettes

Although destructive distillation of bagasse was easily and quickly accomplished, problems were encountered in briquetting. Initial attempts on briquetting were by pressing, using 5 to 13% (by weight) molasses or starch for binder. These attempts were not successful and, after drying, the briquettes were fragile and easily shattered.

Attention was then directed toward the use of sodium silicate "N" binder (Philadelphia Quartz Co.), which prove more suitable than either the starch or molasses. Even with the sodium silicate, briquettes were lacking in essential structural strength after drying. For initial sodium silicate testing, pressures of approximately 1000 pounds per square inch were used.

Experiments were next directed toward the use of sodium silicate "N" with compaction by impact. For these tests, mixtures of water, sodium silicate (up to 6% by weight), and charcoal were placed in a 2-inch pipe and compacted by blows with a 25-pound iron piston which fitted snugly into the pipe die. Briquettes produced by this technique were superior to any previously formed by pressing.

Tests were then made with compaction when using Swift's protein colloid, Fluid Z-2236 Binding Aid, Swift and Co., Chicago, Illinois. With this binder (3 to 5% concentration by weight), hard, dense briquettes were easily produced which, after drying for 12 hours at 80-100°F, were comparable in texture to commercial charcoal briquettes.

For initial tests on briquetting, the moisture content was 20 to 30 percent, as recommended in the literature. These moisture levels were entirely unsatisfactory, and the charcoal remained too dry for successful briquette formation. Water content was then increased until the moisture content of the wet charcoal-water-binder mixture was 60 to 62%, and at this concentration briquetting was easily accomplished. Attempts to form briquettes with various binders at moisture contents of 50 to 55% were then initiated but were uniformly unsuccessful. Our findings on moisture levels for successful briquetting were two to four times those previously suggested and a lower moisture content resulted in a dry mixture which would not form durable briquettes.

For the molasses (which had been recommended by Othmer and Fernstrom), tests were conducted at levels of between 3 and 6% in terms of dry charcoal weight. At the 6% concentration, satisfactory briquettes could be prepared, but these tended to soften with time due to adsorption of moisture from the air.

Further, to produce more commercially acceptable charcoal briquettes, experiments were conducted when using various coating materials. Briquettes were sprayed or dipped into several commercially available binding agents which are dust inhibitors. The resulting briquette had a thin, hard surface, with excellent characteristics. Sprayed briquettes were very clean and could be rubbed on clean white cloth or bond paper without soiling. Similar tests with regular commercial grade charcoal soiled hands and resulted in heavy smudges.

The briquettes produced were also found to ignite more easily than conventional charcoal; spraying heavily resulted in coatings with excessive smoking but thin coatings burned with a clean, clear flame and caused the briquettes to ignite without the addition of external heat or the use of lighting fuels.

Tests on Heat Value

The heat value of the bagasse charcoal briquettes was established as 15,000 BTU/lb. This is completely in accord with expectations considering the carbon content and the degree of compaction. A field test indicated that the briquettes burned at 945°F and were completely satisfactory for conventional use in cooking hamburgers and produced excellent coals.

Discussion on Charcoal Production

The destructive distillation of organic matter such as wood and bagasse is an exothermic chemical reaction which produces heat. Because no oxygen is involved in the reaction, the heat is produced without the discharge of gases or other air pollutants. The principal flammable constituents of the gas distillate are carbon monoxide and methane, both of which burn with a colorless flame.

In an attempt to increase the production of usable heating gas and to increase the rate of destructive distillation with optimum "activity" for the resulting charcoal, most tests were conducted at carbonization temperatures of 500°C or higher. Temperatures of 400 to 600°C resulted in a charcoal yield of 30%, as compared to the reported maximum 52% yield of Othmer and Fernstrom[5]. These higher temperatures did not materially increase gas production and the gas yield was just over one cubic foot per pound dry bagasse destroyed, or about 400 BTU gas heat value per pound bagasse. Gas production for use in sugar mill boilers or for other purposes does not therefore appear to be a by-product of large commercial value for bagasse carbonization, though it is a useful fuel supplement.

As mentioned earlier, dry bagasse is constituted of about 43 to 48% carbon. Since charcoal is largely (90% or more) carbon, maximum yield from dry bagasse could not average 50% if all carbon were converted to charcoal. There are also several important carbon losses, including carbon converted to carbon monoxide, methane, and carbon dioxide in the gas fraction and into acetic acid, methanol, acetone, and tars in the distillate. Because of the limited initial carbon fraction in the raw, dry bagasse and because of the carbon losses which result from destructive distillation, the approximate 30% yield noted in these experiments is more realistic for a relatively pure carbon charcoal than the 45 to 53% values reported by Othmer and Fernstrom[5]. It should be noted, on the other hand, that a slower rate of distillation (2 hours or more for Othmer and Fernstrom as compared to 15-20 minutes here) with lower operating temperatures (325 to 350°C for Othmer and Fernstrom compared to 500°C or higher for this report) can result in increased charcoal yield and possibly in the production of a low-carbon charcoal which burns at a low temperature. A test for one hour's duration at 325°C did result in charcoal production of 39% (as compared to 30% average for most tests), but the bagasse tended to be deep brown rather than black.

For the more normal 30% charcoal production, and with 14,000 BTU per pound charcoal, the resulting heat value is 4200 BTU per pound bagasse carbonized. With 400 BTU value for the gas captured and with 8000 BTU per pound of initial dry bagasse, some 3400 BTU are noted to have been lost to the distillate or to the exothermic chemical reaction. Presuming that 1400 BTU of the initial 8000 BTU remains in the distillate, the exothermic reaction provides approximately 2000 BTU per pound of initial dry bagasse. The combined heat value of the exothermic reaction plus heat value of gas is about 2500 BTU or 30% of the initial heat value, a substantial supply.

Any further study on charcoal production should therefore include a rigorous investigation of heat value, with the objective of determining the total exothermic heat which results from destructive distillation. This heat source, together with that from the gas would be especially inviting since it produces energy without air pollution. For the gas, combustion products are carbon dioxide and water only, and laboratory experience has indicated that the gas burns with a hot, blue flame. The exothermic chemical reaction does not result in the discharge of gas or particulate matter, and the heat supply is therefore truly "pollution free."

Economics of Charcoal Production

Charcoal is now sold in Hawaii and California at wholesale for between 6 and 7 cents per pound. With 30% yield and 6 cents per pound charcoal, dry bagasse would be transformed into a product worth approximately 1.8 cents per pound of dry bagasse or $36 per ton. Millrun 44% moisture bagasse would result in a material valued at $20 per ton. Charcoal production would be a feasible outlet for excess bagasse, selling for $2 to $4 per wet ton, and somewhat higher prices for the raw bagasse material might be possible if a return is additionally available from methanol, acetic acid, acetone, tar, and salvaged heat.

Economics of charcoal production suggest that an ample supply of low cost bagasse and improved technology are essential to the successful development of a charcoal industry on the islands. Rapid distillation of the bagasse over a 15- to 20-minute period of carbonization, automated equipment requiring limited manpower, and good marketing are additionally essential to economic success. Komarek-Greaves and Company, Nichols Engineering and Research, and BSP Corporation are now the leading producers of charcoal producing equipment and provide complete plants including operating advice and assistance in start up.

Manpower for a one ton per hour plant should be reduced to three operating personnel or less (as compared to nine suggested in EPCA Report No. 13). The plant should be preferably located at or close to an existing sugar mill to reduce handling costs and for utilization of surplus heat from the distillation process.

Marketing information for Hawaii indicates that the state consumes approximately 5.9 million pounds of charcoal briquettes annually, or 2,950 tons per year in commercial and recreational use. This market is civilian only and does not include any consideration of the military market in Hawaii which represents almost 25% of the population. Thus a one-ton-per-hour plant operating on a five-day week basis would not fulfill the states own needs. Operating on a two shift per day basis, an excess of production for export would result. In the light of 7 million tons of bagasse total waste each year, this is but a drop in the bucket. However, about 4.2 million tons of the waste are burned for power and the remainder poses serious problems in disposal for, if spread on the ground, it may take more than 15 years to break down. Conversion to compost requires 120 days and quantities of nitrogen supplements to insure breakdown. Open burning has resulted in numerous complaints as well as threatened suits at law for damages.

The cost of a one-ton-per-hour carbonizing and briquetting plant has been bid at $310,000 for one supplier and $500,000 for another. These include a spare parts inventory and local construction of non-automated equipment.

A required working capital of $100,000 has been calculated based on a 4000 ton per year profitable manufacturing level. On a 45-day cash flow basis with average monthly accounts receivable of $45,000 to $50,000, working capital is therefore based on approximately 2.0 times the accounts receivable.

The cost of production of the charcoal based on a no-cost raw material (a true waste) is approximately 1.1¢ per pound. Purchase of the raw material at a value of $10 per ton, its value in equivalent oil to the mill would raise production cost to 1.6¢ per pound.

A current survey of the charcoal market in Hawaii reveals the lowest price retail for charcoal is 7.7¢ per pound. The market prices vary from 7.7 to 10.5¢ per pound. Thus the mark-up between producer and retailer is a factor of 7.

Currently the wholesale price of charcoal in Hawaii is 86 to 88% of the retail price, which means that the cost to the retailer is 6.6¢ per pound. There is no real effort on the part of the retailer to push the product. The retail price of 10.5¢ per pound offers the merchant a return of 33% and results in both better advertising coverage and "pushing" of the product in specialty stores.

A retail marketing specialist for a national grocery chain has indicated that if the product can be sold at 6.5 to 6.75¢ per pound with a 33% profit to the retailer, i.e., a wholesale price to the retailer of 4.4¢ to 4.53¢ per pound, that the local market could be doubled by "pushing" the product and that he, in his chain, would conceivably control 90% of the market by just the factor of a better profit.

Production of a superior grade charcoal by use of coating and other techniques similar to those described here should be additionally helpful in establishing a mainland market. The EPCA Report has suggested emphasis on "sugar charcoal" from the "island of paradise" and this approach may be useful. Addition of small quantities of the tar residual to the charcoal might also be helpful to suggest a unique product; the distillate has pungent "smoked bacon" odor which is pleasant when added in moderate concentrations. Other and useful approaches leading to the development of useful and unique charcoal briquettes will undoubtedly suggest themselves after commercial charcoal production is established.

BIBLIOGRAPHY

1. Deerr, Noel, "Cane Sugar", Chapter XXIII, pp. 445-455 (1921).

2. *Planters' Record*, Vol. 51, No. 1, pp. 110-118 (1964).

3. Gastroch, E. A. and Lynch, D. F. J., Agricultural by Products Laboratory, Ames, Iowa. "Cost Evaluation of Bagasse for Industrial Utilization," *Facts About Sugar* (June, 1939).

4. Kents, James E., *Riegels Industrial Chemistry*, Reinhold Publishing Co., N. Y. (1962).

5. Othmer, Donald F. and Fernstrom, George A., "Destructive Distillation of Bagasse," *Industrial and Engineering Chemistry*, Vol. 35, No. 3, pp. 312-317 (March, 1943).

6. Hawaii Economic Planning and Coordinating Authority (EPCA) Report No. 13, (December, 1956).

Recent Trends in National Legislation — For the Total Protection of the Environment

HONORABLE BOB CASEY (D)
United States House of Representatives

There is a saying that if you live by the sword, you will die by the sword. By the same token, it might be said that if we live by continued advanced technology, will this same technology bury us or save us in our present environment?

There is no question but what a rapid technological advancement in the manufacture of goods, new products, and new methods have contributed to the contamination of this world of ours. In the 19th century, you were not worried with exhaust fumes, for those were the horse and buggy days. A few street sweepers took care of the transportation pollution of that day. When the wooden vehicle of that time wore out, it was usually burned in the family stove — while the "one-horse power" motor of that vehicle went to the glue factory. With modern technology, we now have a 400 horsepower mode of transportation. If it has worn rings, it leaves a trail of smoke that no street sweeper can gather up. When it ceases to run, its carcass may be left at the side of the road by the last owner and strangers will pick what parts are usable from its torso. The rest is left to clutter the countryside.

Our technology is such that millions of these automobiles are made each year, and each is destined to end up in beloved antique splendor or some unsightly heap, leaving someone wondering what to do with it. Our technology has developed tin cans for which there is no use after their contents have been depleted. "No return bottles" mean no youngsters gathering them up from the side of the road to make a little pocket money, and as one of my colleagues from a whiskey producing state said, "The federal government contributes to pollution by not allowing liquor bottles to be refilled so that there is no salvable value to them." The same technology which has brought forth these problems of our environment holds forth the only hope for their resolution.

Simply put, our problem is this: We have, with little compunction, defiled our environment. And, unless rapid steps are taken to correct it, our environment is about to repay us in kind.

In this fight for the total protection of our environment, there is no such thing as a "Johnny-Come-Lately." Those of you who have been in the forefront of this fight — a rather lonesome position — welcome with grateful appreciation the growing support of the people — of state and local governments, our scientific community, business and industry, and the media of the press. We, in Congress, welcome all this help, and I say, Help, because legislative acts alone are not the solution. Our problem is complex, and the answer to it must be found in all fields of endeavor. It will require a concerted and vigorous effort and cooperative programs at all levels.

Our problems began in earnest during the grim days of the Depression. Jobs were needed. The great plumes of smoke and the gushing streams of waste from re-opening factories were viewed with full appreciation by a tired and hungry nation. Then came the war and the tremendous demand for the defense effort. Peace came, and millions of veterans were dumped on the market demanding jobs. The great post-war boom brought jobs and prosperity — and in the scramble for industrialization, our states and communities offered huge tax write-offs and a promise to look the other way to get plants to locate within their borders. Through this boom period of upheaval and growth, little, if any, effort was made to protect our environment.

Here, in Harris County, a massive industrial complex grew along our Houston Ship Channel. During eight years of the 1950's, I had the privilege of serving here as Harris County Judge — the head of Commissioners Court, which governs our county. We began to receive complaints from our constituents as to the lack of effort on the part of many of our major industries to control the emission of pollutants, both liquid and particulate. We were told that houses were losing their paint in a matter of a few months. Wire fences were corroding. Yes, even some women in certain areas of the county alleged that their stockings disintegrated on their legs.

We searched in vain for state of federal laws and programs to assist us in curbing it. There were none. On our own initiative — we created the first County Pollution Control Program in the State of Texas — we ordered this department to proceed through the County Attorney's office and seek injunctions against the violators. Nearly all did — and I learned an important fact. The cost to industry to design and install pollution control equipment in many cases is prohibitive, often running into the millions. I learned then that we needed the proverbial "carrot," as well as the "stick," to give industry a tax incentive to take corrective action on its own.

When I entered Congress nearly 12 years ago, one of the first major bills I introduced was to give industry this tax incentive. Through the years, I pressed for enactment, but was vigorously opposed by the Treasury Department, concerned primarily with the tax revenue loss.

On December 30, 1969, this tax incentive became law. The provisions of my bill to permit industry to rapidly amortize the cost of such anti-pollution equipment was incorporated in the massive tax revision passed by Congress and signed into law on that day by the President. This provision is a needed factor in our fight to protect our environment, for it encourages business and industry to use some of its resources in this bill. Rest assured that if this "carrot" does not do the work, Congress will be inclined to apply the "stick." In fact I have heard some who have reviewed pending legislation say that this could be better categorized as a "club."

There is a reason for this attitude, just as there is a reason for the President suddenly deciding on February 10th that environmental controls are needed. Congress — and the Presidency — are much like a mirror. They both reflect to a considerable degree the interest, and the concern, of the people. And the concern today is that we move swiftly to protect our environment and reverse the decades of ravaging we have permitted or ignored. And the people expect you to do it now, immediately.

There was no large-scale public outcry during the 1950's, and this lack of concern was dutifully reflected by Congress. During that decade, only two major laws dealing with environmental pollution and control were enacted. In 1955, the Public Health Service was given an appropriation of $1 million and authorized to conduct a research program into air pollution. In 1956, the Federal Water Pollution Control Act was passed, authorizing a five-year $50-million a year grant program to aid communities in building sewage treatment plants. Those two programs expressed the sum total of our national concern for protection of our environment in the 1950's.

I can well recall discussion with the president of a big paper concern in early 1960, when he was stating that research needed to be done on water pollution, that although the paper industry was spending some money, the federal government was not doing its share in regard to water pollution research. This was hard for me to believe, but upon checking, I found, at that time, there was only $50,000 a year for research in water pollution.

As our national problem became more critical — as public indignation deepened — as those of us, who had searched in vain for federal laws to help, made our voices heard — Congress acted. Like a mirror, it reflected this national concern through legislative enactment of a number of new laws and programs during the decade of the Sixties.

In 1960, the Surgeon General was directed to study one of the great sources of air pollution — the automobile — and his report laid the groundwork for motor-vehicle-exhaust standards first instituted in 1968. In 1961, the Water Pollution Control Act was heavily amended. Funds were increased to $100 million a year, enforcement was extended to navigable as well as interstate waters, project ceilings were lifted to $600 thousand, research funds increased, and the program was placed under the authority of the Surgeon General.

Two years later, the Clean Air Act of 1963 became law. It gave the nation a three-year program of research and technical assistance, and the first federal abatement procedures in cases of interstate air pollution. Then came the Clean Air Act of 1965, revamping this program. It regulated motor vehicle emissions, set procedure for abatement of international air pollution, and established additional research programs. In that year, we also passed the Water Quality Act creating the Federal Water Pollution Control Administration and placing it under the Interior Department. We increased research and upped construction grant funds to $150-million. A major provision, however, was authorizing mandatory standards for quality of interstate waters.

But for those in attendance today, perhaps the most important act passed by Congress in 1965 was the Solid Waste Disposal Act. This marked the beginning of the federal interest in this rapidly growing problem. It authorized programs of research, training, and grant support for demonstration projects. Unlike the federal effort in air and water pollution, the objective of the Solid Waste Disposal Act, at least so far, has not tended toward regulation. Rather, it is directed toward the goal of finding ways of disposal without creating health hazards or environmental contamination, and in recycling waste products into productive channels.

The Solid Waste program is a joint venture between the Departments of Interior and Health-Education and Welfare. H.E.W. administers the program and its efforts are largely in areas seeking new technology in incineration, sanitary landfill, rail haul, recovery and re-use, and composting. Interior is primarily concerned with solid wastes resulting from the extraction, processing, or utilization of minerals and fossil fuels. It concerns itself primarily with three major categories: municipal wastes, mine tailings, and scrap.

As an example of the research being done, let me tell you of a letter I received from Agriculture officials a few days ago. It was typed on paper made from 40-percent garbage — rags and paper reclaimed and recycled from a municipal dump. A small, but significant, achievement in finding productive use of a waste product which contributes heavily to air pollution of our communities.

Some of my Congressional colleagues are suggesting methods of collection of the solid wastes. Some of them are quite intriguing. One proposes that each new automobile have added to its price a $50 junking fee so that the last owner is always able to get $50 out of his junked automobile by turning it into a collection center. Now he does not say what to do with the automobile after it is collected, but at least that is his proposal for keeping them from being abandoned in the woods or at the side of the road. Similarly, another colleague proposes a 2-3 cent refund on beer cans and bottles, whether they are reusable or not, hoping to either stop the throwing of cans or bottles on our highways or to encourage some industrious youngster to go around collecting them for a turn-in price.

In 1966, in answer to the demand for greater help, Congress passed the massive Clean Water Restoration Act. It authorized $3.4-million for research and development and three-million-dollars for studies of estuaries. All ceilings were removed, and communities could receive as much as 55-percent federal aid on a project. For the first time, the tremendous reservoir of scientific and technical talent in industry was brought into use, for authority was given to make research grants to industry. We also amended the Clean Air Act during 1966, expanding it to a three-year $186-million-dollar program, and authorizing grant aid to local control programs.

The following year, Congress again completely revamped the Clean Air Act. We established machinery for air quality control criteria, for air quality control regions, and provided for federal action if the States failed to act. We earmarked $125-million dollars for research on fuels, and $303-million-dollars for grants to states, local agencies, and training and research. The decade of the Sixties closed with Congress enacting, on December 22, 1969, the bill to establish the Council on Environmental Quality. This may well be one of the major environmental measures enacted during the last decade. Under it, we created a three-man board, charged by the President with the responsibility to be "the keeper of our environmental conscience and a goad to our ingenuity." It has four major responsibilities: to study the condition of our Nation's environment, to develop new environmental programs and policies, to coordinate the wide array of federal environmental programs. But most important of all, it was given the broad power and authority to see that *ALL* activities of the federal government take environmental considerations into account.

This is going to be an extremely busy group if it must put its stamp of approval on every project containing federal funds or involving federal lands, or licensees. Part of our great problem — and one we, in Congress, have been pushing to resolve — is the fragmentation of environmental control programs throughout the federal establishment. Few people realize that at present there are thirty-eight separate federal agencies involved, in some way or another, just with water and water resources.

New Year's Day, 1970, the day our act creating this Council was signed into law, officially opened what we, in Congress, term the "environmental decade." Some experts figure that is about all the time we have left to solve our problems — to get our world in order. To get a massive legislative effort underway, a number of us in Congress sponsored legislation to create a Joint Committee on Environment and Technology. This will be composed of two members from each of the major standing committees of the House and Senate. We know, as you do, that no one can be an expert in all fields of pollution, and that the final answer to our problem will be as complex and diverse as the factors which created it. We also know that solutions will come from new technology not at this time known, and the application of known technology from other endeavors which were not pollution oriented, such as the technology developed in our space program.

The President, as I mentioned, submitted a number of major legislative recommendations to Congress on environmental control on February 10, 1970. Hearings are now under way on many of them. I must say that the Congress has been ahead of the Executive in its desire to remedy some of our deficiencies. Congress authorized an expenditure of one-billion-dollars while the Administration requested only $214-million. We refused to accept it, for many states and communities had committed or expended funds for waste treatment facilities on the promise of federal reimbursement. In fact, we increased the appropriations to $800-million dollars for this year, which the President subsequently promised he would expend.

The Administration has, in fact, seen the light — and the determination of Congress. Ironically, one of the proposals submitted a few weeks ago was for a four-billion dollar, four-year program, for construction of municipal waste treatment plants. From $214-million to four-billion, in my opinion, is a considerable increase in enthusiasm — and I welcome it.

The trend in Congress is toward tougher laws in dealing with pollution of our environment and with those who defile it. We have reached the position that those who do so, and not the public, must pay the massive costs of cleaning it up, or face heavy penalties.

An example of this is the conference report awaiting action on the Water Pollution Control Act amendments — and it is tough. Oil spill offenders, for example, would be made liable for up to $14-million dollars for the cost of cleaning up their mess. Federal agencies or *licensees* would be forbidden to pollute navigable waters. It deals with the discharge of other hazardous substances, with acid mine drainage, and Great Lakes Pollution.

Here, then, is where we stand at the opening of our "environmental decade." Our problems are many and they are complex; but they are not insurmountable. All of us here today have one ultimate goal in this fight, and it can be achieved. But it is going to require the cooperative effort of the federal, state, and local governments. It is going to require the help of business and industry, of our scientists and technologists, and of our people. We need a massive overhaul and consolidation of the federal effort, we need the establishment of federal standards on environmental contamination and protection, and we need vigorous enforcement at the local, state and federal levels. We need more funds to pay the massive costs for current and future programs, and stronger support from the Administration. The trend in Congress, as it is in the nation, is toward total protection of our environment. And I am one who believes that it is not a moment too soon. While it is not too late to seek "that newer world," time is rapidly running out on the old.

Some Political and Economic Implications of Industrial Waste Recovery: A California Study

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INTRODUCTION

Background

The greatest asset possessed by the State of California is its environment. By virtue of its natural beauty and diversity, California has prospered until today it is the richest, most populous, most technologically advanced state in the Union. It is paradoxical, therefore, that as the State aspires to even greater eminence, the aesthetic qualities which contributed to the State's growth are now in jeopardy as a result of its success. The State's population explosion, urbanization, and technological expansion are all harbingers of suffocating influences to the environment.

California recognizes the magnitude, complexity, and urgency of the various factors that are adversely affecting its natural environment, and concern for their effective solution has been prompt. The Governor, Executive Branch, Legislature, and the appropriate agencies of the State have publicly dedicated themselves to preserving, restoring, and promoting the highest environmental quality attainable. As an example: the Comprehensive Health Planning Act of 1966, Public Law 89-749, states as a policy goal the achievement of "an environment which contributes positively to health." The legislation establishing the Environmental Quality Study Council of 1968 stated, "improvement of the quality of California's physical environment consistent with the maximum benefit to the people of the State is a matter of state-wide, regional, and local concern calling for coordinated public and private action in the interest of health, safety, and welfare of present and future generations." This concern has manifested itself in the establishment of specific legislation and standards by state councils and ancillary organizations in an attempt to protect the environment. In these efforts to date, the principal emphasis has been placed upon air and water pollution. Unfortunately, a third pollutant, equally important and an intrinsically interrelated despoiler of the environment, remains to be adequately addressed and controlled: solid waste.

The extent of the solid waste management problem is, unfortunately, not as obvious to the average citizen as air and water pollution. Solid waste will soon reach unmanageable proportions if positive action is not taken on a statewide basis to change the existing fragmented management pattern. The magnitude of California's problem might be better visualized by recourse to some startling statistics generated in 1967:

- The municipalities, industry, and agriculture of California generated an estimated 70.5

million tons of solid waste. This averages about 20 pounds per resident per day.

- There were 716 general-use solid waste disposal sites in the State and less than 10 percent of them were considered sanitary landfills; i.e., 90 percent were dumps of various sorts harboring rats, flies, odors, etc.
- Thirty-three disposal sites were found to be discharging solid wastes directly into surface water.
- Open burning dumps were allowed in the majority of the counties of the State.
- Agricultural waste was the largest source of solid waste in the State, over 50 percent. However, it was not even accepted for disposal by landfill operators nor were there any regulations or provisions for its management.

The foregoing data were published by the California Department of Public Health in 1968 in an in-depth appraisal of the status of solid waste management in the state of California. The report verified that the status of solid waste management is inadequate to permit the preservation of the quality of the land, air and water resources at current levels, and a resultant encroachment on the health and well-being of the people of the state is occurring. Overall deficiencies, viewed on a state-wide basis, include:

- Fragmented authority
- Inadequate planning
- Nonexistent or inadequate standards
- Primitive technology
- Inadequate financing

Governor's Task Force Organization

In view of the urgency and complexity of the problem, Governor Reagan, on April 10, 1969, established the Task Force on Solid Waste Management to evaluate the problems of solid waste in California and to recommend a course of action for the state. The Task Force was drawn from a cross section of public-spirited citizens representing business, industry, the professions, government, and academic sectors. More specifically, there were owners and operators of refuse collection, salvage and disposal companies, a banker, an economist, an architect, lawyers, aerospace technologists, a commissary owner, a surgeon, public officials, etc. Significantly, the Task Force had access to a wide range of viewpoints and expert knowledge, but all were dedicated in a common interest: to help solve the waste management problems of the State.

The Governor requested a broad review of California's solid waste problems with particular attention directed to the following questions:

1. How much solid waste is being generated in California, of what types, and where? What are the projections for the next 25 years?
2. What kinds of problems are associated with collection, transportation, and disposal?
3. What kinds of problems are associated with solid wastes that are not "collected and disposed of" in the usual sense such as agricultural wastes?
4. Are there legal or administrative as well as technological barriers to effective and efficient solid wastes management?
5. Can we afford indefinitely to "bury" solid wastes that should be reclaimed and reused in the interest of resource conservation?
6. What should the state's role be in solid wastes management? Regional or local government? Private enterprise?
7. What are the recommended short term and long term solutions with respect to the various classifications of solid wastes generated within the state?

The Task Force was urged to work closely with other units of state government having solid waste interests, and to complete its review by January, 1970. In order to respond to the specific charge of the Governor and because of the wide scope of the contributing problems, the Task Force was organized into six Working Groups, as shown in Figure 1.

- Generation and Production
- Storage Collection and Transportation
- Disposal and Land Use
- Governmental Relations
- Technology
- Hazardous Wastes

The Working Groups operated in parallel in an effort to delve as deeply as possible into each of the foregoing segments of solid waste management. They obtained and assimilated representative literature in the field, conducted interviews with trade associations and consultants, and attended seminars and conferences. The groups met and exchanged pertinent results on a regular basis.

No single group was specifically concerned with industrial waste recovery. However, the subject of reuse and recycling pervaded the investigations of every group. For this reason, the entire summary of the findings of the Task Force by problem area is included here as Appendix A.

Regional Approach to Environmental Quality

In the summaries of problem areas and recommendations, there are two recurring themes which will be pursued here in greater detail. The first is

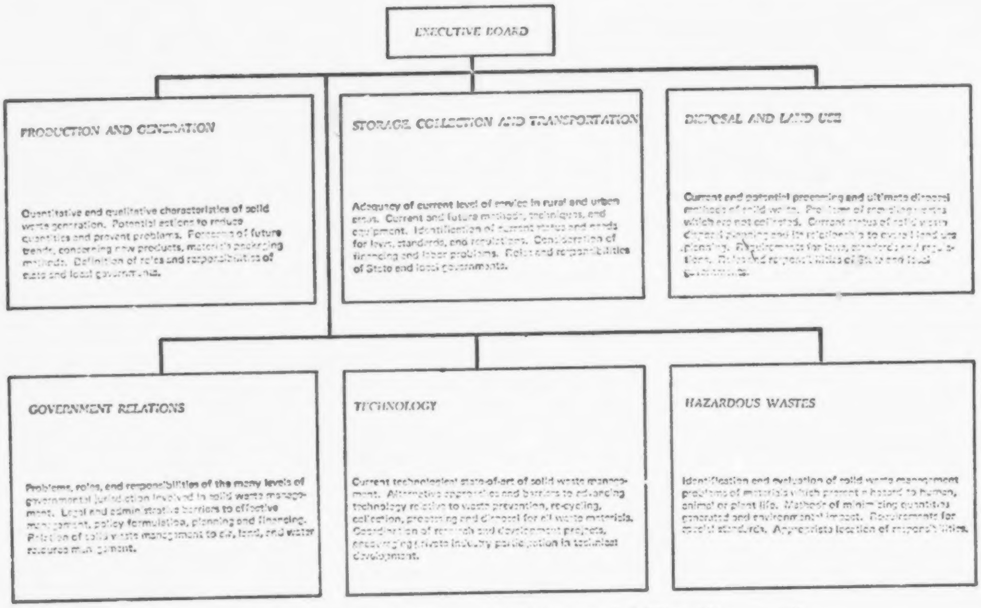
EXECUTIVE BOARD
PRODUCTION AND GENERATION
Quantitative and qualitative characteristics of solid waste generation. Potential actions to reduce quantities and prevent problems. Forecasts of future trends, concerning new products, materials packaging methods. Definition of roles and responsibilities of state and local governments.
STORAGE, COLLECTION AND TRANSPORTATION
Adequacy of current level of service in rural and urban areas. Current and future methods, techniques, and equipment. Identification of current status and needs for laws, standards, and regulations. Consideration of financing and labor problems. Roles and responsibilities of State and local governments.
DISPOSAL AND LAND USE
Current and potential processing and ultimate disposal methods of solid waste. Problems of abandoned wastes which are not collected. Current status of solid waste disposal planning and its relationship to overall land use planning. Requirements for laws, standards and regulations. Roles and responsibilities of State and local governments.
GOVERNMENT RELATIONS
Problems, roles, and responsibilities of the many levels of governmental jurisdiction involved in solid waste management. Legal and administrative barriers to effective management, policy formulation, planning and financing. Relation of solid waste management to air, land, and water resources management.
TECHNOLOGY
Current technological state-of-art of solid waste management. Alternative approaches and barriers to advancing technology relative to waste prevention, re-cycling, collection, processing and disposal for all waste materials. Coordination of research and development projects, encouraging private industry participation in technical development.
HAZARDOUS WASTES
Identification and evaluation of solid waste management problems of materials which present a hazard to human, animal or plant life. Methods of minimizing quantities generated and environmental impact. Requirements for special standards. Appropriate location of responsibilities.

Figure 1: Organization of the Governor's Task Force on Solid Waste Management

that environmental quality problems should be handled on a "problem-shed" basis which do not necessarily coincide with political boundaries. Consequently, it is recommended that the responsibility for air, land, and water pollution control and solid waste management be divided between state and local government as follows:

The program at the State level should centralize policy formulation; provide overall direction and guidance; coordinate state and local efforts; emphasize conservation of resources; develop environmental objectives and standards; and stimulate improved technology.

The program responsibilities at the local level (city, district, county) should be consistent with the policies and standards of the state and should basically include localized policy establishment and administration, detailed planning, operation and control, and financing of local solid waste programs and systems. Some counties will have to seek regional solutions, not only for its obvious economic advantages, but out of pure inability to afford the costs. Therefore, the Task Force recommends that the counties should publicly endorse the development of "regional" concepts.

The second theme is that the level of funding for research and development for solid waste management is wholly inadequate to meet the political and societal demands placed on the waste generators and the public agencies. A major cause for this is directly attributable to the fact that, currently, assessments of the intrinsic value or cost of waste pollution do not enter into funding level and/or allocation decisions.

In this section, some vexing political, econnomic, and societal aspects of the pollution control will be presented. Conceptual views of a regional waste management system and an integrated benefit-cost methodology for budget allocation among the four areas of environmental quality, air, land, and water pollution control and solid waste management, will be presented and discussed.

Political, Economic and Societal Aspects of Pollution Control

A major governmental obstacle in dealing with pollution control is due to the fact that air, land, and water are, in part, a common resource, and, in part, subject to individual possession or ownership. Traditionally, in this country, individual rights to water and air have been tied to the ownership and use of land. For pollution, as for other aspects of land-use control, planning, zoning, and standards have become the most commonly employed tools to effect a compromise between private property rights and the public interest.

Under the current system, the authority to implement these land-use controls rests with local governments — counties and municipalities. This fragmentation of land-use controls is a fact of political life. It means that the Federal Government, the States, and regional authorities concerned with pollution must develop devices to deal with local governmental jurisdictions.

The fact that air, land, and water pollution are interrelated and should be considered in an integrated item has recently been gaining recognition. At the Federal level, there are many people calling for a new and expanded charter for the Department of Interior where the major environmental engineering operations could be brought together. Others say that a new department is needed. In a like manner, Governor Reagan's Task Force on Solid Waste Management recommended that "At some future time, a Department of Environment, covering all aspects of land, air, and water resources, should be established". Figure 2 illustrates the fragmented responsibility for waste control as it exists today.

A second problem arises from attempts to assign the costs of control of pollution to the industries that produce it. For example, charge on polluters for use of the public air supply as an atmospheric sewer has been widely advocated. But this must be implemented on a national or, at least, regional basis, otherwise polluting industries may simply move from one state or municipality to another one which uses its lack of pollution control as a recruiting inducement for industry.

Air and water pollutants do not recognize conventional political demarcations. They ignore city and county lines and state boundaries. To limit or prevent pollution, therefore, control measures are needed over regions determined by meteorological and hydrologic realities, airsheds, and water basins, rather than by legal artifacts. The entire urban-suburban-rural complex that constitutes a modern metropolis must be treated as an entity. Existing levels of government need to cooperate in new ways, and it may be necessary to invent and test new types of governmental organizations.

Some precedents already exist for regional governmental organizations. Regional water management has a traditional standing in the United States — from the early, single-purpose sewage, irrigation, or drainage districts to such modern multipurpose organizations as the Ohio River Sanitary Commission (Orsanco) and the Delaware River Basin Commission (DRBC). In Germany, the Ruhr Valley Administration has shown that regional pollution control based on systems analysis and economic optimization can be carried very far in practice, through cooperative organizations, prudent engineering, and ingenious use of workable but theoretically sound rules of thumb. Orsanco and DRBC have achieved considerable progress toward basinwide planning and management for abatement of pollution. In California, responsibility for regulation of water

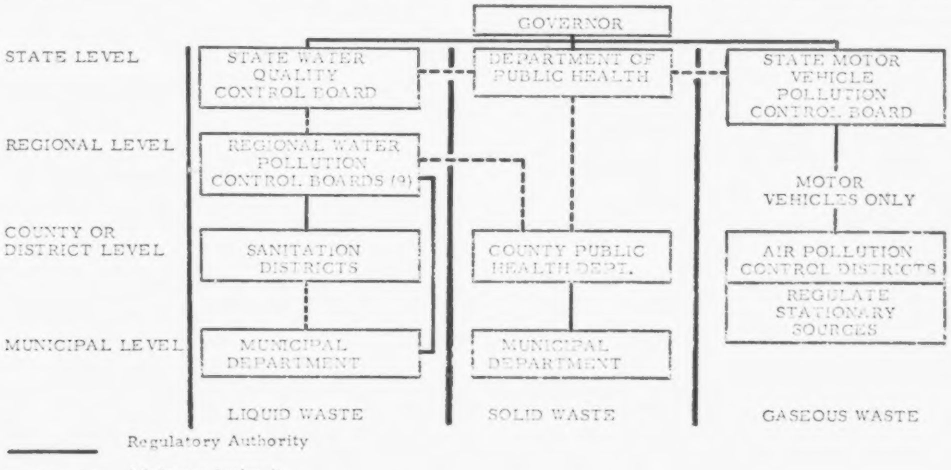
GOVERNOR
STATE LEVEL
STATE WATER QUALITY CONTROL BOARD
DEPARTMENT OF PUBLIC HEALTH
STATE MOTOR VEHICLE POLLUTION CONTROL BOARD
REGIONAL LEVEL
REGIONAL WATER POLLUTION CONTROL BOARDS (9)
MOTOR VEHICLES ONLY
COUNTY OR DISTRICT LEVEL
SANITATION DISTRICTS
COUNTY PUBLIC HEALTH DEPT.
AIR POLLUTION CONTROL DISTRICTS
REGULATE STATIONARY SOURCES
MUNICIPAL LEVEL
MUNICIPAL DEPARTMENT
MUNICIPAL DEPARTMENT
LIQUID WASTE
SOLID WASTE
GASEOUS WASTE
Regulatory Authority
Advisory Authority

Figure 2: Fragmented Responsibility for Waste Control

quality is vested in nine Regional Water Control Boards.

Like education and economic opportunity, controlling pollution will be expensive. An Assembly select committee estimates the cost at $3 billion to $5 billion over the next five to ten years to improve and protect California's environment. Among other things, it recommended a $5 million solid waste R and D program on a crash basis. But, pollution control is not an end in itself. The quality of life depends only in part on the quality of the natural environment. Economic growth, a high standard of living, and national security are also ingredients.

Society must use its environment in a variety of ways, and limited environmental resources must be allocated optimally among different uses. Hence, the basic issue in considering problems of pollution is to define goals and priorities. In order to do this, it is necessary to find ways of balancing aesthetic, recreational, and related aspects of the quality of human life against other values. Stated in economic terms, how much will people pay, and how much should they pay, for these intangibles? How clean should this stream (or air) be, at what cost, for what purpose, and at what future time? It is meaningless simply to say that the stream (or air) should be "clean".

To reduce the costs and maximize the benefits of pollution control, it is necessary both to consider the choices for different courses of action within the environment as a whole, and to take full advantage of its natural processes. For example, garbage disposal by incineration, landfill, or household grinding adds pollutants to the air, the soil, or the waters. The choice of which methods to use should depend on the character of the local environment and the total burden of pollutants presently being added to different parts of it. In windy areas that are steadily ventilated, e.g. San Francisco, a higher proportion of waste products can be disposed of to the air than in regions of light winds and frequent inversions, e.g. Los Angeles. Different streams may be devoted to different purposes. Some can be kept clean and sparkling, others used to oxidize relatively large quantities or organic matter. Waste recovery and reuse must be considered explicitly.

The production-consumption cycle has an intimate interaction with the population residing and/or working in the vicinity of industrial enterprises. This interaction is caused by the introduction, into the environment, of those wastes which are not recycled, either for economic or technical reasons. The induced wastes are of two fundamental types: hazardous and non-hazardous.

The influx of non-recycling hazardous wastes causes changes which degrade the quality of the environment and/or disturb the ecological balance thereof. These degradations, in turn, arouse the awareness and concern of the population. Soon, pressure groups form; hearings are held; and the legislative process begins. Then laws are enacted and stringent regulations are imposed on the "polluter".

These stringent regulations, if enforced, result in higher co for waste disposal and are reflected in the industry's balance sheets as a higher operating cost. The "polluter" should then reexamine his decision of what and how much of his hazardous wastes he should recycle, or, at least, process to reduce the level of hazard, based on higher cost of disposal. Too often, though, the rise in the cost of disposal occurs either too slowly so as not to be noticed or too quickly so as not to leave adequate time for consideration of alternatives. In either case, therefore, the result is, generally and perhaps erroneously, to continue the existing disposal practices and just pay the additional cost without considering the alternatives.

Some industries are disposing of wastes in such a manner and in such a degree of hazard that significant degradation of the environment, as well as personal injuries and fatalities have occurred. Under each of the SIC codes, for example, some type of hazardous waste is being generated. Recent surveys in California indicated that large amounts of waste are being produced by industries with large percentages of hazardous wastes, e.g. chemical industry (SIC 281) $\approx$ 16.1 tons per employee/year and petroleum refining (SIC 2911) $\approx$ 23.5 tons per employee/year.

The large amounts of hazardous wastes will surely increase in the future. The Federal Government, as well as the States, and, even counties and municipalities are expected to enact legislation which will severely limit the quantities and characteristics of hazardous wastes which can be disposed of by present-day methods.

Industries recognize that the economic collection and disposal of their solid, semi-solid, and liquid wastes will be a requirement for their continued growth. But, they also realize that stringent air, water, and soil pollution standards on their wastes will probably have an inhibiting influence on their continued growth. For these reasons, major portions of the chemical industry in Los Angeles County, responsible for more than half of the total State production, are considering relocation to sparsely populated areas, and an exodus has begun to San Bernardino and Riverside Counties. One wonders if it might not be cheaper in the long run to develop processes for recycling wastes rather than to move away. Further, will there always be some other place to move?

A Regional Waste Management System

In California, several stringent standards have been set with respect to air and water pollution. These standards have resulted in higher costs for many industries. In comparison to air and water, there are few standards in the field of solid wastes. In January 1970, the legislative process concerning solid wastes began at the state level. Three distinct sources of information will be brought to bear on the resulting legislation. In addition to the Task Force Reports, the Department of Public Health and an Assembly select committee have each issued final reports. All call for waste management and control. All advocate it on a regional approach.

The concept that pollution of air, land, and water is really a single problem manifested in three distinct ways did not enjoy much acceptance prior to publication of "Waste Management and Control", in 1966. The report marked a departure from conventional thinking about pollution problems by supporting the view that efforts to deal with the challenges of air, land, and water pollution can be wholly successful only if they are consolidated into a single attack on the generation, management, and recycling of wastes. A conceptual view of a total waste management system required to bring about various desired levels of environmental quality is depicted in Figure 3. This system can be described in terms of simplified block diagrams of inputs and outputs.

Generators

Organic and inorganic materials enter the production cycle as fuel, food, and raw materials. These are partly converted into final goods and partly become waste products. Except for increases in inventory and recycling, final goods also ultimately enter the waste stream of a typical urban environment.

The final generators, then, take the forms of municipalities (including residences), vehicles, industries, and agriculture. Each of these, except the vehicle, produces waste products: liquid waste, solid waste, and gaseous waste.

On-Site Processing

There is evidence that considerable recycling of industrial wastes is being practiced. Unless, and until, these wastes impinge on the environment, this recycling is *not* considered in the accounting scheme of the waste management system.

Considerable on-site pollution control via processing is being performed by industry. This is the bulk of the items considered in the waste management accounting system.

On-Site Disposal

Several industries practice on-site disposal. These disposal methods vary from lagooning of liquid wastes to landfill of solid wastes. Deep-

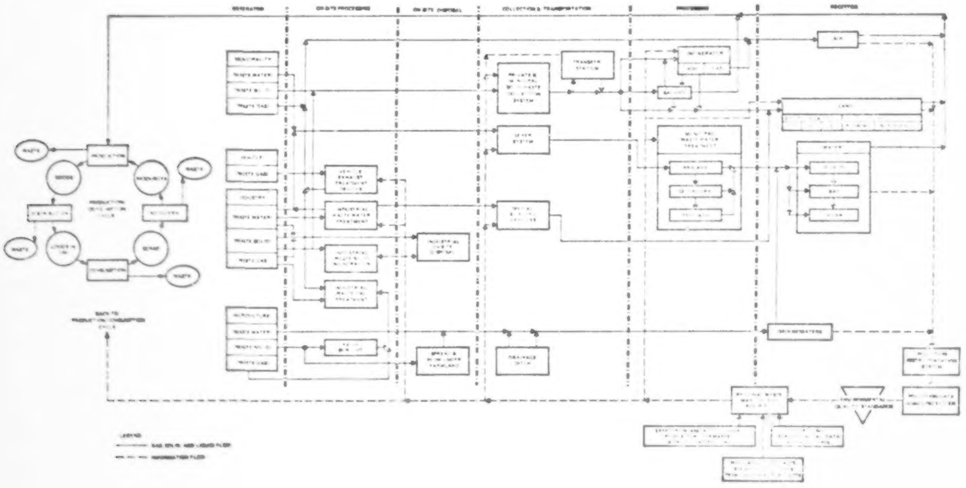

Figure 3: A Conceptual Regional Waste Management System

well injection is also practiced in many areas of the country.

Collection and Transportation

The collection and transportation systems vary from vehicular to sewer systems. Ninety-five percent of industrial and municipal solid wastes are collected by packer trucks using one, two, or three man crews. In some instances, a transfer station is used. Economics of potential salvage and distance from the processing/disposal site are factors in this latter consideration.

Processing

The main methods of processing are incineration and municipal waste water treatment. Methods of processing, such as composting and/or salvage are being practiced, but, the quantities involved are so minute that they are not even considered here.

Receptors

The principal receptors or sinks of waste are: air, land, and water. But, since each of these is also a resource, air, land, and water eventually find their way back into the production-consumption cycle.

Regional Waste Management Agency

The postulation of a regional waste management agency affords an informational feedback loop to the system. A pollution monitoring system feeds data into the pollution control cycle. These data are then compared with the desired environmental quality standards. Climatic and meteorological forecasts, and people's attitudes and values serve as external sources of data to the decision-making process. The Agency would have the power to perform long-range planning, e.g. purchase and set aside landfill sites for future use; short-range planning, e.g. the establishment of temporary transfer stations or daily operations, e.g. closing down an industrial incinerator if the air pollution standards were exceeded on a given day.

A regional waste management agency will need a competent technical, planning, administrative, and legal staff. In addition, it must have adequate authority and resources to deal effectively with its responsibilities. These include:

(1) Investigations of actual or potential pollution problems and development of effective plans. To do this, the agency will need to obtain and interpret physical, biological, and economic data to forecast the occurrence and extent of pollution, and to analyze the economic and other consequences of alternative courses of action.

(2) Control and regulation of pollutant emitters — for example, industrial discharges into a river system or combustion exhausts into the atmosphere.

(3) Taxation and assessment, both for control purposes, through charges on polluters, and for raising funds to carry out the purposes of the agency. The effluent charges levied in the Ruhr Valley are an example. Besides such revenues, the agency may also need to raise money by issuing bonds or by obtaining grants from the Federal Government.

(4) Establishment and operation of treatment or disposal facilities.

(5) Cooperation with, and advice to, other governmental agencies, especially municipalities and counties, which have authority over land use.

An Integrated Methodology for Budget Allocation

The specific question which must be answered by regional decision-makers is just how much health, comfort, happiness, etc., are the people of that region willing to trade off for economic gain? To answer this question, it is necessary to have some scale for benefits versus costs, or cost versus disaster or potential of disaster; only then can risk be assessed and a level of regional environmental quality be accepted or rejected by the residents through their administrators.

In the past, environmental questions have been attacked on a piece-meal basis. In particular, air pollution, land pollution, water pollution, solid waste management, insecticide use, and transportation planning have each been studied in isolation. This implies either that there are no links between the relevant systems or that any links which do exist are adequately represented by market prices. Adequate representation by market prices, in turn, means that these prices represent marginal social costs and not simply marginal private costs. That these necessary conditions for piece-meal management decision to be "optimal" do not, in fact, pertain, may be illustrated by two simple examples.

Consider the problem of air pollution from particulates and sulfur compounds resulting from fossil fuel combustion. Assume an engineer is charged with devising an "optimal" air pollution control plan for a given region. One treatment option may very well be wet-scrubbing of stack gases with subsequent discharge of the scrubber effluent to a nearby watercourse. In his framework, there is no charge for this discharge. The stream is someone else's problem and, furthermore, the engineer has no information on the water pollution effects of the discharge. Similarly, the water manager commonly ignores the external costs associated with either land disposal or incineration of sludge from biological waste treatment units. That such external cost may be far from negligible is clear from the fact that municipalities are having increased difficulties in locating future solid waste disposal sites without running into fierce legal opposition from affected local residents. Incineration of the sludge will introduce particulates and gases into the atmosphere and may exchange part of the old water pollution problem for a new air pollution source.

Lack of funds is a major reason behind the discrepancy between concern and action. With local and state tax bases and borrowing capacity heavily strained, only the Federal Government seems to have the necessary flow of funds to finance sewage treatment works and new methods of dealing with solid wastes. Yet appropriations in these areas have been minimal, although President Nixon has recently pledged a $10 billion program for sewage treatment works.

An indication that the President advocates an integrated approach was suggested in his February 10, 1970 message to Congress. He outlined a 37-point program for restoring the quality of the environment. Air pollution control, water pollution control, land resources, and solid waste were ascribed to be interrelated. It will be a significant accomplishment if the measures suggested can all be enacted. But, there are many measures which should be considered as inter-related and intra-related.

Conceptually, what is needed is an integrated methodology that will allow a decision-maker to view a single curve (more likely, a series of lines, sometimes with abrupt changes in slope and with step changes in value) indicating the expected benefits for any given level of expenditure for environmental quality. Also indicated should be the projects in which funds should be invested and the level of funding.

At present, society is unable to strike a meaningful balance between the costs and benefits of preventing pollution because it cannot measure adequately the psychic and physiological effects of a dirty environment. Consequently, decisions are generally based on estimates of immediate monetary expenditures rather than on evaluations of the total benefits and costs of different courses of action. Regional air pollution control expenditures, for example, are presently being justified on the basis that the regional cost of controlling pollution is more than offset by the regional benefits received from its control. At present, while the costs of air pollution control are being assessed realistically, the calculation of benefits is only partially complete: the only item included is the prevention of residential soiling costs. The sum of all the benefits is actually several times greater than the benefits of prevention of residential soiling costs.

The benefits of improving environmental quality arise from reducing environment pollution damage to human health, animals, plants, and structures; from expanding recreational opportunities; and from appealing to aesthetic sensitivities. Some of these benefits are difficult to measure and often these measures cannot be converted into common measures or dollars. The more difficult areas are measuring aesthetic enjoyment and improvement of human health. However, estimates of the total worth of a human life, made by HEW for their evaluation of disease prevention programs (1966), may be helpful here.

Setting aside the difficulties in measuring the total benefits and total costs for each of the four areas, for the moment, it is interesting to proceed to the budgetary process. Briefly, the objectives of the budgetary process are: (a) to achieve the distribution of the total budget among various programs (a program is a group of activities that provide services directed to the attainment of the same policy objectives) or activities (a part of a program) that will most efficiently and effectively further the government's explicitly stated policy objectives; (b) to insure that the benefits expected from expenditures are weighed against their cost in taxation or other economic burdens imposed on the economy; (c) to obtain economy and efficiency in the conduct of existing operations.

Fortunately, the problems involved in achieving the environmental quality budgeting objectives are quite similar to those problems encountered in achieving the budgetary objectives in such fields as health. In the health field, for example, the budgetary problems were solved in the following manner:

> Starting from a given distribution of expenditures, the recommendations to be made are: Activities should be expanded, contracted or eliminated. The relevant considerations are: (1) Is the operation as efficient as possible? If not, can it be made more efficient? (2) Does expenditure on this activity exceed, equal, or fall short of the worth of the services provided? (3) Is the return-to-expenditure ratio of the activity greater than, equal to, or less than the return-to-expenditure ratios of other activities of the same program. The listing of efficient activities will lead to alternative

total program recommendations at various levels of total expenditure.

The same recommendations must be made concerning programs; therefore, the same questions should be raised and the same methods used. Even if the amount of increase or decrease cannot be determined in these cases, the direction, increase or decrease, should be clear. The proper level of expenditure may be best approached through successive approximations over several budget periods.

When the size of the sector has been decided, reconsideration is given to allocation among programs. When the total allocation to each program is decided, allocation among activities is reconsidered.

The same iterative budgetary approach is applicable to the environmental quality problem. In the latter case, the program budget and its allocation to environmental quality are set (thus, selecting the "point on the benefit versus cost curve"). Then the environmental quality budget is allocated to each, air, land, and water pollution abatement programs and solid waste management, (on an incremental benefit-cost basis) and the results for the system are monitored. In the following budget period, the various values are changed, again starting at the program level and working down through the allocation process. After several such iterations the preferred balance is established.

Systems Engineering Approach to Waste Management

It is now of interest to compare the resources required for environmental quality improvement by air, land, and water pollution control and solid waste management. This comparison is properly made on the basis of incremental environmental quality improvement per increment of value as a function of value. Figure 4 depicts a schematic of the methodology. For purposes of illustration, the Solid Waste Management arm has been described in detail. The concepts apply equally to the Air, Land, and Water Pollution Control arms. These, then, are the individual contributors to the quality of the regional environment.

The development of the system requires first, an analysis phase (separation of the problem into its constituent parts or elements) and second, a synthesis phase (combination of parts or elements so as to form a whole). Solid waste management has three principal sources: municipal, agricultural, and industrial. The California Department of Public Health categorizes municipal wastes into residential, commercial, demolition, and special wastes; agricultural wastes into manure, fruit and nut crops, and field and row crops; and industrial wastes into food processing, lumber, chemical and petroleum, and manufacturing. These, in turn, have been divided into types: garbage, paper wastes, inert wastes, etc. or into combustible, noncombustible; grindable,

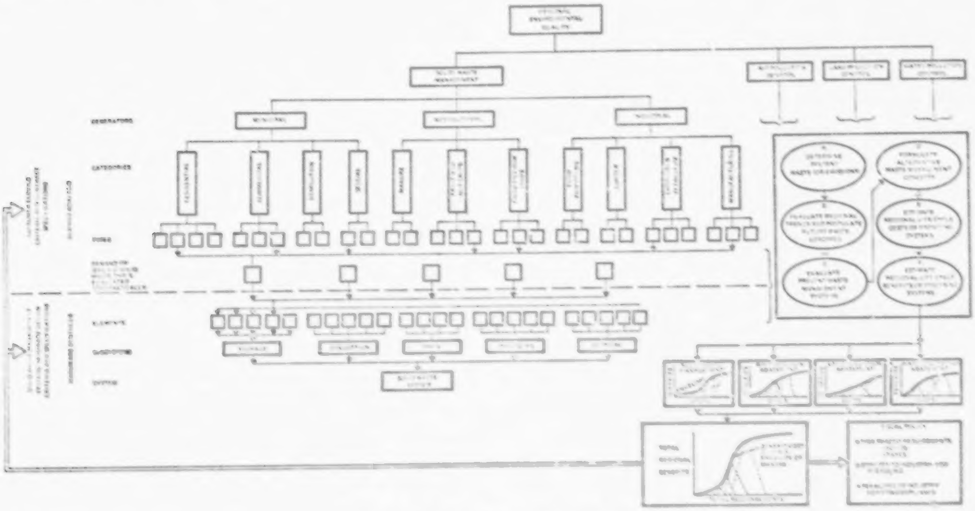

Figure 4. Schematic of the Methodology

non-grindable; etc. Figure 5 considers six (6) states which describe the "types" of solid wastes, for collection and disposal purposes.

Figure 5 also provides a vehicle for the transition from the "Demand Analysis" to the "Hardware Synthesis". From this flow diagram, approximately 250 alternative systems can be formulated. Initially, as complete a list of alternatives as possible should be developed. This list should then be screened to eliminate those that are clearly inferior or are not applicable to the particular region under study. The remainder should be closely analyzed and evaluated in terms of the goals, objectives, and criteria of the study. The final decision should not be made in isolation, however, but should be made in the overall context of environmental quality of the region and based on total regional benefits and total regional costs.

Returning to Figure 4, it can be seen that a similar systems engineering procedure can be followed for each of the contributors to environmental quality. Except for inserting the word "emissions" for "waste" in the case of air pollution control, the procedure is rather standard. Present waste loadings must be determined; future waste loadings must be postulated. The present waste management system must be evaluated to determine if it is performing adequately and/or if it can be adapted to meet future requirements, e.g. for the next twenty years. Alternative waste management concepts should be formulated for storage and collection, as well as for processing and disposal. Regional life-cycle costs and benefits then, must be estimated for the promising alternative systems.

Considerable subjective judgement should be used in estimating regional benefits. For, as has been said before, total benefits include intangibles such as aesthetics, noise, odor, vectors of disease, political implementability as well as direct and indirect capital and operating costs and salvage potential. More research and application, especially the latter, should be performed in the use of expert opinion in the development of total regional benefits and in the explicit evaluation of alternatives. Some fairly good methodologies have been suggested; a few of the more promising are under development.

The optimal benefit-cost relationship for, say, solid waste management is described by the envelope of maximum benefit as a function of cost for each of the promising alternative systems. Similar curves can be estimated for each of the other contributors to environmental quality. The curves can then be combined, mathematically, to describe an optimal benefit-cost surface which is constructed from the envelopes of the maxima. A state or regional policy-maker could then use this curve to aid in allocating his budget among the waste management program and transporta-

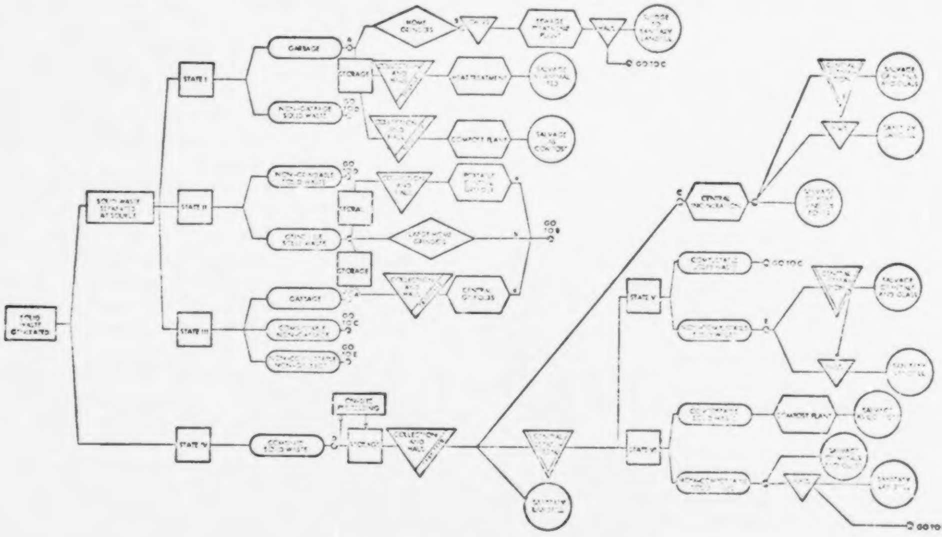

Figure 5: Solid Waste System Flow Diagram

tion, law enforcement, and other competing requirements.

After a decision is made, either as to level of total regional benefits, or, level of regional expenditure, a "theoretically" unique point on the surface is defined. This then "theoretically" allows the optimal allocation of resources among air, land, and water pollution and solid waste management. In a world where uncertainty of outcomes is a fact of life, the iterative procedure is probably more implementable than a mathematically selected optimum for all these alternatives. But, this integrated methodology is a goal for which society must strive. If this methodology just narrows the region of iteration, it will have achieved more benefit than its total cost.

CONCLUSIONS

The following are the major conclusions derived from the authors' (a) intensive study of the Governor's Task Force of Solid Waste Management and (b) individual and collective research into a systems engineering approach to solid waste management, for the purpose of describing some political and economic implications of industrial waste recovery.

1. The basic areas of deficiency in solid waste management in the state of California are: (a) fragmented authority and lack of coordination, (b) inadequate planning, (c) inadequate standards, (d) primitive technology, (e) insufficient financing, and (f) no comprehensive monitoring program.

2. The problems of air, land, and water pollution control and solid waste management are each being treated separately.

3. The present climate for industrial waste recovery is, in general, economically unfavorable.

4. Political and social pressures are increasingly intolerant of pollution.

5. The political and social pressures should evoke legislation to provide incentives and impose penalties to bring about uniform levels of environmental quality, on a national, or, at least, a regional basis.

6. The responsibility for air, land, and water pollution control, and solid waste management be divided between state and local governments as follows:

(a) The program at the state level should centralize policy formulation; provide overall direction and guidance; coordinate state and local efforts; emphasize conservation of resources; develop environmental objectives and standards; and stimulate improved technology.

(b) The program responsibilities at the local level (city, district, county) should be consistent with the policies and standards of the state and should basically include localized policy establishment and administration, detailed planning, operation and control, and financing of local solid waste programs and systems. Some counties will have to seek regional solutions, not only for obvious economic advantages but out of pure inability to afford the costs. Therefore, the Task Force recommends that the counties should publicly endorse the development of "regional" concepts.

The duties of the local, regional, and state agencies are described in Appendix A.

7. Decisions concerning the allocation of funds among the four areas mentioned above, for environmental quality improvement, should be made in the context of an integrated benefit-cost analysis.

8. Inevitably, waste prevention, recovery, and reuse must become an integral part of a regional waste management system.

APPENDIX A

Summary of the Findings of the Task Force by Problem Area

A. PRODUCTION AND GENERATION

Problems Identified

1) Accurate data on quantities and characteristics of solid waste produced are generally unavailable and when available are sometimes unreliable. This is particularly true for industrial, agricultural, and other nonresidential wastes.
2) The volume of solid waste generated is increasing at a greater rate than population growth. The types and varieties of waste are continually changing. Consumer goods from reusable to disposable, limited-use items resulting from new manufacturing processes, materials and packaging, and new, difficult-to-manage wastes are continually being injected into the waste stream. Present management methods are inadequate to cope with increasing volumes and types of solid waste.
3) Most levels of government have failed to recognize and assume their public responsibility in dealing with special, hard-to-control, solid wastes. This is especially true of industrial and agricultural wastes.

4) The responsibility of the producer of a product that eventually will become solid or otherwise waste, as well as the responsibility of the user of that product, have not been defined.
5) General awareness of the problems of solid waste production and its effect on the environment is lacking in almost all segments of society.
6) The problem of natural resources in short supply is coming into sharper focus each year and must be considered in waste management planning.
7) Impending legislation and controls imposed by air pollution and water pollution control regions may make methods of disposal which have been utilized heretofore unacceptable in the future due to the interaction with other pollution sources. This may impose sharp increases in waste quantities to be disposed through acceptable public use disposal sites.

Recommendations

The following broad objectives were defined as vital to a recommended program on the production and generation aspects of solid waste management.

1) To create an awareness of the problems of solid waste and generate acceptance of responsibility for proper management of *all* solid waste by government, industry, and the public.
2) To minimize the adverse effects on public health and the environment caused by the generation of all types of solid waste.
3) To encourage maximum reutilization and recycling of waste material in order to conserve our natural resources, and to reduce the amount of waste to be disposed.
4) To encourage the development of improved methods and techniques of producing consumer products, which would create less waste material, or which would improve their disposability.
5) To improve our knowledge of waste quantities and characteristics and develop improved technology regarding materials, handling, reclamation and salvage, and solid waste disposal.
6) To evaluate the waste management problems on a State-wide basis so that waste materials which may have negative value in some areas might be transported to areas where they might have positive worth.
7) To encourage development of new products from waste materials.
8) To rigidly control the management of materials which can become health hazards in their disposal.

Generally the mechanisms for achieving the objectives are: establishment of a responsible agency, regulation, creation of incentives, imposition of taxes, establishment of research and development efforts, and education efforts.

It is mandatory that an organization be established at the State level and charged with the responsibility of solid waste management. The State agency should probably be assigned total environmental responsibility with solid waste management as a primary department and production and generation as a branch of that department.

A comprehensive educational program must be established to make all segments of society aware of the solid waste management problems to include:

- Consumer programs
- School programs
- Industry programs
- Solid wastes information center

Research and development efforts can be performed by existing state institutions such as the Department of Public Health for health-related problems; universities or state colleges in fundamental research; and the private sector, which should be encouraged and financially supported if necessary. Maximum use should be made of Federal grants which could supply financial amplification to the State financial contributions.

One of the most fruitful areas where research should be directed is in the development of automatic materials separation techniques to improve the economics of salvage and reclamation.

While the secondary materials industry of California — scrap metals, forest products, paper goods, etc. — are engaged in the recycling of resources, industry in general should be further encouraged to engage in research and development of recycling resources. The mechanism for such encouragement could be State and Federal grants. In addition, emphasis should be directed toward design of packaging with materials that can be reclaimed and recycled.

B. STORAGE, COLLECTION, AND TRANSPORTATION

Problems Identified

1) In general, collection service is provided in the metropolitan and in many suburban areas

of the State. In most of these areas, government actively concerns itself with the level of collection service by specifying "minimum" levels of service. In the unincorporated and sparsely populated areas of the State, collection service is generally inadequate, and in some of these areas collection service is nonexistent.

2) While most "owner-occupied" residential properties in the State subscribe to a regularly scheduled refuse collection service, many rented individual units and multiple dwelling units in various parts of the State are not currently receiving adequate refuse collection service.
3) As population increases, land available for sanitary landfill operations is becoming scarcer. As existing disposal sites adjacent to the larger metropolitan areas are exhausted, the use of disposal sites farther removed from the source will become more prevalent. This will result in the need for large and expensive "transfer" facilities and equipment. These expenses, coupled with the expenses resulting from the stringent requirements and operational standards, will make disposal costs for many smaller communities almost prohibitive on an individual bases.

Recommendations

1) For health and aesthetic reasons, it is highly desirable for all persons in the State to be provided with a minimum level of service by a regulated refuse collection service. Thus, it is recommended that, in order to assure the provision of a "minimum" level of collection service to all persons in the State, a State-wide standard should be issued which requires every individual dwelling unit in the State to have at least once-a-week refuse collection service. (This standard is similar to the requirements presently being enforced in some of the larger cities.) It is further recommended that owners of rental property be required to provide adequate facilities and services for refuse collection and that the owner of the property should be financially responsible for the provision of collection services.
2) Responsibility for the enforcement of this minimum standard should be delegated to the counties. Collection service requirements vary from area to area and county to county depending on specific area characteristics such as temperature ranges, weather problems, types and volumes of wastes created, population densities, seasonal population changes, road networks, etc. Additional service standards and regulations, tailored to local problems, should be developed by the counties, or by the cities, or by both in combination. These standards would apply to additional service frequency above the State minimum, type of services to be provided, type of containers, etc.
3) It does not appear possible to provide a minimum level of collection service to the rural and sparsely populated areas of the State at a reasonable service fee (due to the long distances that must be driven between collection stops). Thus, to achieve an adequate level of service for residents in these areas, some form of subsidy may be required.
4) Refuse collection agencies should be subject to minimum State-wide standards for refuse collection operations. These standards may be supplemented at the county level, if required. For example, vehicle safety standards should be set at a State level. Minimum standards for workers' safety and sanitation could also be established at the State level, and improved (if required) by the county or city. Rate setting and actual enforcement of collection standards and regulations should be at the county or local governmental jurisdiction where the collection service is operating.
5) Any contractor desiring to offer his services to a community should be able to prove responsible ownership, financial capability, experience, adequate equipment, and all other factors deemed necessary to provide the service required by the community. Contractors meeting these standards should be licensed by the county or possibly by the State.
6) "Open competition" for refuse collection is, in a sense, an American tradition. However, should open competition continue to prevail, it will be almost impossible to enforce standards and to provide an adequate level of service at minimum cost. In order to provide adequate, regulated service at minimum cost (with effective enforcement), franchises and contracts might be put out to bid for geographic areas on the basis of providing "total collection service." To attract qualified contractors and to encourage investments in improved capital equipment,

facilities, and technological development contracts should be of long-term duration (possibly 10 years).

7) Some counties will have to seek regional solutions for refuse disposal, not only for its obvious economic advantages but out of pure inability to afford the costs. Therefore, it is recommended that the counties should publicly endorse the development of "regional" concepts. The county's role should also include assistance in the acquisition of sites for transfer stations and landfills, financial assistance if required, and public endorsements of all the steps necessary to assure their residents are provided with adequate, economical collection service.

C. DISPOSAL AND LAND USE

Problems Identified

1) Comprehensive legislation for solid waste is inadequate, and authority and responsibility for disposal practices are fragmented. Minimum regulatory and operating standards for many parts of the State have not been formulated. Thus, city, county, and private practices lack coordination and in many instances are in direct contradiction.
2) Awareness is lacking on the part of both the public at large and local governmental agencies of the extent to which present disposal practices are degrading the environment, threatening public health, and destroying ecological balance. (In the absence of a clear understanding of the problem by governmental agencies and the public at large, resistance to standards which will increase disposal costs can be anticipated.)
3) Further research into the technology of solid waste disposal is needed.
4) Relationships between the privately and governmentally owne ,ectors of the disposal industry need to be structured to encourage the investment of risk capital for technological innovation, land acquisition and planning, and improved services by the private sector of the industry.

Recommendations

The Task Force is particularly concerned with the existing fragmented authority of State and local agencies and is of the opinion that there is urgent need for the development of a comprehensive solid waste management program.

1) The State should, insofar as possible, centralize authority for controlling all aspects of solid waste management in a single unit of State government in order to avoid fragmentation and duplication. The minimum level of local planning, inspection, and supervision should exist at the county level, and preferably at the regional level.
2) The designated State agency should be empowered to develop and establish minimum standards for the disposal of all solid wastes. These standards should cover the handling of wastes, location and operation of facilities, and design and planning criteria. These standards should be related to urban and rural population density variations and should be "open ended" to allow continued review and revision as necessary. Special standards for the handling and disposal of agricultural and certain industrial wastes should be included.
3) A continual inventory of disposal facilities should be maintained. In addition to gathering information on geographic locations, restrictions, operating practices, physical conditions of site, etc., the State should determine the specific identity of the persons responsible for compliance with regulations and standards for each site.
4) An advisory group should be appointed by the Governor to assist in the formulation and revision of minimum State-wide disposal and operating standards. The composition of such an advisory group should include informed citizens, State and local officials, professionals from such fields as sanitary engineering, ecology, economics, public health, municipal planning, land use, disposal system operation, etc., along with representatives from affected public and private concerns.
5) Any disposal operating or planning standards that involve any portion of waste disposal into the atmosphere should be reviewed and approved by the appropriate agency responsible for air quality of the State. Any waste disposal operating or planning standards that involve the underground, surface, or coastal waters of the State should be similarly reviewed by the appropriate State agencies concerned with protecting the water resources of the State. In those areas where consideration of air and water pollution are involved, serious priority should be given to the long-range ecological effects to the State's environment rather than short-term economic

dislocations which might be involved. (If necessary, economic subsidy might be considered where environmental quality control creates serious economic losses.)

6) Legislation is recommended that will require every county or multi-county regional authority to develop a master plan for adequate solid waste disposal facilities. All local master plans should be reviewed and approved by the designated State agency. Criteria for approval or disapproval of plans should include:
    a) Conformity with minimum State standards
    b) Consideration of all forms of solid waste generated within the area
    c) Provision for future disposal facilities which are consistent with projected population growth and industrial expansion
    d) Compatibility of the proposed master plan with those of adjacent local jurisdictions
    e) Integration of the solid waste disposal plans with the area's overall master plan for land uses, circulation, and public services.

    Particularly for high density urban areas where disposal sites are becoming scarce, special plans which consider regional transfer stations that efficiently utilize truck and rail transportation systems, technological innovations that result in increased capacity of disposal sites, and a rational salvage and reclamation program should be formulated.

7) Land use planning for disposal landfills, disposal transfer stations, or processing facilities should be consistent with sound planning standards for harmonious land uses. Consideration should be given to factors such as sufficient buffering or screening between noncompatible land uses, adequate circulation requirements, and a reasonable end-use of disposal sites which have been filled.

8) Where a potential disposal site is considered by local agencies to be the most desirable, and where such a site is in conformity with State and local standards, the local agency should be vested with the power of eminent domain to acquire such a site and either resell or lease such a site to private disposal operators on the basis of competitive bidding by individuals or firms qualified by experience and financial resources.

9) Inasmuch as sound planning requires reliable data on the rate of disposal generation, uniform and reliable measurements of waste material are needed. Such data should be considered public information to assist all levels of public and private planning and to provide the quality of data which will encourage "risk capital."

10) The designated State agency should develop a comprehensive public education program which will alert the public to the hazards of inadequate disposal systems and to the need for solid waste disposal systems which will not endanger their health and environment.

11) Improved technology and standards will require a higher degree of skill in operation of facilities and programs. The State should provide technical training programs for operators, program managers, and solid waste officials.

D. GOVERNMENT RELATIONS

Problems Identified

1) Only 16 of 58 couties have developed some form of master plan. Many of these are deficient or incomplete, some have not been implemented, and none have considered all of the types of wastes produced. Cooperative planning is greatly lacking between cities and/or counties, and no mechanism exists to encourage or require cooperation.

2) Solid waste management appears to be a regional problem, and no centralized authority exists at the State level to stimulate regional approaches or encourage cooperation.

3) Improved solid waste handling and disposal systems will require greater direct costs. While the larger systems can generally absorb these costs, many smaller programs find it financially difficult to absorb the capital costs of improved systems. The initial cost-hurdle of land and equipment acquisition appears to be a major problem. While it appears that the State should require counties to prepare master plans for solid waste management, there is no financial planning grant or loan programs for solid waste in existence to aid in developing these plans.

4) No comprehensive standards for solid waste management exist at the State level and no agency has authority for setting such standards. Relatively few counties have adopted standards for solid waste disposal, and some of these are not enforced uniformly or not enforced at all.
5) Fragmentation of authority has made it difficult to provide uniformity in establishing regulations. Enforcement has also been difficult. Cooperation is frequently lacking between local jurisdictions. No State agency has primary responsibility for solid waste management. The result has been an uncoordinated, piecemeal set of laws and policies established by individual agencies, and applicable only to their own narrow field of interest.
6) A large number of local jurisdictions have failed to assume or recognize any responsibility in planning for or assuring sanitary and efficient management of solid wastes.
7) Lack of public awareness of the problems and needs of solid waste management has seriously hampered solid waste program efforts. Information regarding solid waste management is vital to planning and program efforts. No mechanism exists at the present time for periodic inventory, surveillance, and gathering of this information.

Recommendations

It is recommended that responsibility for solid waste management be divided between State and local government as follows:

The program at the State level should centralize policy formulation; provide overall direction and guidance; coordinate State and local efforts; emphasize conservation of resources; develop environmental objectives and standards; and stimulate improved technology. Specifically, the State should:

1) Serve as the focal point for developing basic policies regarding solid waste management and its relationship to public interest, health, welfare, and the environment.
2) Develop solid waste planning guidelines; review and approve county plans for consistency with State policies, and coordinate county plans into regional or State-wide, long-range solid waste management plans.
3) Develop and adopt minimum State standards for the storage, collection, transportation, processing, disposal, and utilization of solid wastes, and establish an effective means of enforcement.
4) Provide technical assistance and consultation on solid waste management for the benefit of local, public, and private agencies within the State requesting such assistance.
5) Conduct studies related to solid waste management in both the public and private sectors. These studies may be conducted by the State independently, or jointly with another agency, or by contract, and may utilize State, Federal, or contract funds for this purpose.
6) Encourage, coordinate, and finance solid waste research and technological development studies and projects in the State; evaluate new or improved methods of solid waste management, and serve as a source for exchange of information regarding these efforts.
7) Establish a continuing program of surveillance and monitoring regarding solid waste management practices in the State, and maintain a current inventory of solid waste generation facilities and practices. This inventory will be a source of information for all interested agencies and persons.
8) Establish and maintain liaison with Federal solid waste programs, including coordination and administration of research and planning, as well as administration of solid waste loan or grant programs.
9) Carry on a continuing program of training and public education regarding solid waste management.

The solid waste program responsibilities at the local level (city, county, district) should be consistent with the policies and standards of the State and should basically include localized policy establishment and administration, detailed planning, operation and control, and financing of local solid waste programs and systems. Specifically, within their jurisdictions, these agencies should be responsible for:

1) Assuring that all solid waste systems comply with all applicable State and local standards and ordinances, and providing necessary inspection services therefor.
2) Determining the methods of disposal to be utilized, as well as the locations of disposal facilities, provided these do not conflict with the policies and standards established by the State.
3) Developing detailed, long-range plans for solid waste disposal within the boundaries of their respective jurisdictions. These plans

may be made jointly or individually; however, the county should have the responsibility for developing an overall, coordinated plan (which should include plans of applicable cities or districts) for the entire county. The plan should be submitted to the State for review and approval.

4) Developing, adopting, and enforcing local ordinances governing storage, collection, transportation, and disposal of solid wastes. These ordinances shall not be in conflict with the minimum standards established by the State, but may be more restrictive and comprehensive if desired, as long as they are not unreasonable or discriminatory.
5) Assuring adequate operation of collection, transportation, and disposal systems either directly, by private firms or by agreement with another jurisdiction. This may include the regulation of collection agencies; establishment of collection areas; establishing the type and level of service, permits and franchises, and other administrative functions.
6) Assuring ways and means of adequately financing local solid waste management programs.

It is further recommended that:

1) The State develop a loan or grant program to aid counties in the preparation of solid waste master plans and to stimulate cooperative regional approaches.
2) A uniform permit system for solid waste disposal facilities be developed and administered by the assigned State agency or its authorized representatives.
3) The State develop a comprehensive program of public information, education, and training.
4) An advisory group representing the public and all solid waste interests should be appointed to assist the State agency in carrying out its duties.
5) State and local government should encourage the reclamation and recycling of solid waste in order to conserve our natural resources, and reduce the cost of solid waste disposal.

It is recognized that agricultural wastes create serious problems; however, we make no specific recommendations. It is suggested that agricultural wastes be the subject of a special study by appropriate State agencies, and that as soon as possible, a comprehensive Statewide program be established to alleviate the health hazards and environmental quality problems caused by agricultural wastes.

E. TECHNOLOGY

Problems Identified

1) Existing technology for solid waste management is clearly inadequate to the changing needs, and lags that of other pollution sources such as water or air by many years. Changes that have occurred have been small steps and have come about only by virtue of extreme pressures which were required to keep the system from breaking down. Some specific aspects of the problem are listed below:
    a) Although landfill is used to a predominant degree in California, the ever increasing demand for land and skyrocketing value mean that new techniques for disposal or more efficient use of landfill must be developed.
    b) An accurate assessment and projection of waste production and disposal is generally unavailable. Making such information available will provide a basis for defining the research and development needs and will provide lead time for technological advances.
    c) We are facing natural resource shortages in the future which define a need for recycling or reclamation of the waste materials. Considerable effort must be devoted to research on wastes prevention and wastes utilization.
    d) Advances in the use of more automated collection equipment are needed to make significant economies in the costliest of the solid waste management functions.
    e) The primary methods of solid waste disposal have been variations of burying or burning, but significant improvements in these methods have not been made.
    f) Development of new equipment for compaction or particle size reduction will increase efficiency of collection equipment and landfill requirements.
    g) Little attention has been given to the agricultural waste problem.
2) To successfully mount a large-scale program to overcome technological gaps requires an intensive coordinated and comprehensive effort involving Federal and State governments, local and regional public agencies, universities and research organizations, and private industry groups.

There appears to be a deficiency in coordination in relation to overall planning of national and State research, development and planning of solid waste programs, university grants, matching city grants, and industrial activity. In California, there is no State agency currently given responsibility for this coordination.

3) Lack of basic data on current aspects of technology has hindered research and planning. There is no central data bank so that what information is available is not properly disseminated. This creates a gap between researcher and user.
4) There is a gross lack of education throughout the field. Solid waste management has suffered from lack of prestige as an occupation and has therefore had difficulty in attracting qualified professionals to the field. Inadequate information on the solid waste problems and ill-defined goals for a plan have resulted in public unawareness or apathy; therefore, politicians have lacked the impetus to expend funds on technology.
5) The interaction of the technological problems of the pollution areas of air, water, and solid waste are becoming better understood but are generally treated independently.
6) A major cause of the difficulty of getting acceptance for a research and development program is that there is no direct way of assessing the intrinsic value or cost of waste pollution. Since waste generally has no direct economic value, the logic for expenditure of funds for technological advancement is not purely economic. The reasons may be subjective and relate to such things as reduction in land insult, aesthetics, disease, odors, etc.

Recommendations

1) In many cases, collection and transportation are handled by small operators who cannot invest in research to improve the efficiency of their activities. There is no real motivation for the private investor to do more than meet minimum specifications. While many new ideas and concepts may have potential merit, local governments with limited budgets for solid waste management cannot risk expenditures of public money to test out unproven concepts. Demonstration and development of these techniques, therefore, must be financed by private interests or by some means of financial assistance through a public grant program. Some form of incentive to stimulate high risk achievements would attract private sector funding.
2) The conclusions derived from the current state of the art indicate that there are specific technology projects which should receive initial emphasis:
   a) Recycling or reclamation of resources
   b) Reduction of waste at the source
   c) Reduction of total volume of waste by means of efficient compaction or particle reduction methods.
   d) Highly automated salvage systems
   e) Reduction in labor requirements by automation of collection systems
   f) Improved methods of incineration
   g) Advances in economics of utilization of agricultural wastes
3) A central data bank is needed for solid generation data, operational practices, techniques, methods, experience, etc. Most logically, this would appear to be a State function. In the near term, the Public Health Department would appear to be the most appropriate state unit. In the longer term, perhaps a State Environmental Department would be more logical.
4) Although the Federal government spends a great deal of money each year, the State should finance research that is unique to California's problems. The research efforts should be guided by a steering committee of State and private parties.
5) State standards pertaining to all aspects of solid waste management should be continually upgraded to produce improved environmental conditions. This would provide an impetus for technological advances.
6) There has been a general apathy by the public which has only recently begun to change. Although specific local issues often generate a considerable amount of political interest, there has been no large State-wide political movements on solid waste management. Thus, generally, the only items that are controlled are those that have become crucial local problems. A comprehensive State-wide educational program should be established to make all segments of society aware of solid waste management problems. The program should encompass all segments of the society and include consumer programs, school programs, industry programs, and a solid waste management information center.

F. HAZARDOUS WASTES

Problems Identified

1) Rapid acceleration of industrial technology has resulted in the introduction of new and exotic materials into man's environment at an increasingly rapid rate. Little or nothing is known about the effects on humans or the environment of many of these compounds, individually or in combination.
2) Surveillance necessary to prevent deleterious concentrations of potentially toxic compounds at disposal sites and unauthorized disposal of toxic or hazardous industrial wastes is lacking; and chemical substances which could cause long-lasting damage to the environment must be identified and neutralized.
3) Additional research is required to develop information on such factors as leaching, movements of pesticides through the soil, carcinogenic substances and other compounds, chemical reactions of materials, ultimate fate and nature of materials, etc.
4) Information is incomplete in the following areas:
    a) Hazards of human exposure to carcinogenic substances
    b) Interaction of pesticides with solid wastes
    c) Trace element chemical pollutants
    d) Migration of disease organisms through soil
    e) Pathogen detection and treatment
5) Additional information is required before employing widespread use of ocean disposal methods. Research is needed to gain an understanding of the long-term ecological effects of ocean disposal.

Recommendations

1) It is recommended that the designated State agency institute and maintain an accurate inventory and appropriate projections of hazardous solid waste generation. Detailed information should include:
    a) Generation of wastes by location of point of generation
    b) Amount of waste generated by type and degree of hazard
    c) Identification of company ownership and specific identification of the official responsible for disposal
    d) Description of the current means of disposal and identification of the points of disposal or discharge.

    Special attention should be directed to the early completion of detailed field surveys of the following specific problem areas:
    a) Chemical and petroleum industry wastes
    b) Drug industry wastes, including discarded drugs and containers
    c) Syringes and other contaminated or single-use medical supplies as used by physicians, hospitals, clinics, and similar health care facilities
    d) Radioactive wastes
    e) Sewage treatment sludges
    f) Federal and military wastes
2) A vested right cannot be acquired to generate or to dispose of waste into the environment, or to continue to generate or dispose of waste at any particular level of quality, once intiated. Periodic revision and upgrading of requirements will be necessary to adapt to changing conditions. It is therefore recommended that for each class of hazardous wastes, the designated State agency be directed to develop special standards of design and/or operation for collection, storage, transport and/or for disposal sites receiving hazardous wastes and to periodically review and update these standards.
3) Since current monitoring and surveillance programs are inadequate and enforcement will be a greater and more difficult problem in the future, it is recommended that the designated State agency be directed to develop methods of audit and control to assure an adequate level of compliance with the standards.
4) It is recommended that an advisory group composed of informed citizens in the areas of sanitary engineering, ecology, economics, public health, municipal planning, land use, disposal system operation, etc., along with representatives from other affected public and private concerns, should be appointed to work with the responsible agency of the State in formulating the guidelines and/or standards.
5) The designated State agency should conduct a formal reexamination of current radioactive wastes management practices in California to assure that they are adequate in meeting the needs of the State.
6) The designated State agency should study changes in ecology of all the shallow coastal waters off the populated areas of California brought about by the treatment and disposal of sewage sludge.

7) The designated State agency shall conduct surveys of Federal and military waste practices, establish standards, procedures, and regulations for possible incorporation in Federal legislation, and request the support of California's congressional representation in the preparation of legislation to prevent further pollution.
8) In addition to identifying hazardous waste generators and personnel of responsibility in the waste generation process, to assure the adequate and open development of public policy and fair, impartial, and adequate enforcement of standards and regulations, it is necessary to identify all persons of responsibility within the entire solid waste management process. Therefore, it is recommended that as a minimum, licensing and inspection requirements should include the requirement for complete disclosure of all parties engaged in the collection, transfer, transport, or disposal of waste material destined for introduction to the land or water environment of California.

As noted, various classes of hazardous wastes were examined by the Task Force in some detail. Detailed recommendations for these problem areas are contained in "Selected Problems of Hazardous Waste Management in California," and are incorporated by reference in this Task Force report.

Resource Recovery from Incinerator Residue – A Project Report

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INTRODUCTION

If the recovery of resources from wastes is to be successfully achieved in urban areas, it must be compatible with the need for safe, healthful, and economic community solid waste disposal. With this thought in mind, an "Analysis of Factors that Affect Economic Recycling of Ferrous Metals and Other Inorganic Material Contained in Municipal Incinerator Residue" was undertaken, in 1969, by the American Public Works Association with a grant from the U. S. Bureau of Mines. I am pleased to have the opportunity to outline the project scope and to relate certain results to this conference.

Nature and Scope of the Project

It has been estimated that 5 million tons of incinerator residue are produced in the United States each year. This material contains about 1½ million tons of ferrous metals, 100,000 tons of nonferrous metals, and more than 2 million tons of glass. Available information indicated a relatively small portion of these metal and mineral resources is reclaimed. Documentation of readily available information concerning the practical experience of local officials and others concerned was the primary goal of the project. The use of mailed questionnaires was considered. Prior experience of the APWA, however, indicated that personal contact by knowledgeable interviewers offered the best procedure for obtaining information on the experience of municipal officials, private contractors, and industry.

Thus the decision was made to use the case-study technique. The investigation was limited to the metal and mineral contents of municipal incinerator contents of municipal incinerator residues. However, its potential positive impact on the concept of recycling-reclamation of all community solid waste was recognized.

Six case-study cities were selected: Baltimore, Atlanta, Cincinnati, Los Angeles, Milwaukee, and New Orleans. Four of these are port cities which carry on commerce with the Far Eastern, Central and South American, and European markets, as well as the eastern, midwestern, southern, and far western domestic markets. Five of the cities presently practice municipal incineration. Los Angeles, which shut down its municipal incinerators in 1957, was selected because of its history of municipal salvage programs for domestic refuse.

A steering committee was established to give guidance in planning and report preparation. It consisted of two municipal officials with solid waste management responsibilities and two persons with waste reclamation industry experience.

TABLE 1
Municipal Incinerators Operating in Case-Study Cities[1]

City	Annual Tonnage	Number of Plants	Rated Daily (24 Hrs.) Capacity in Tons
Atlanta[2]	242,134	2	1,200
Baltimore[3]	350,520	2	1,400
Cincinnati	335,732	4	1,400
Milwaukee	156,336	3	825
New Orleans[4]	310,000 (est)	4	1,400
Totals	1,395,322	15	6,225

[1] Los Angeles does not operate municipal incinerators.
[2] An additional 250-ton/day furnace scheduled for operation by June, 1970.
[3] A 1400-ton/day Baltimore City-County plant scheduled for construction. This plant will provide approximately 800 tons/day capacity for Baltimore City.
[4] New Orleans is renovating a fifth plant (St. Louis) of 450 tons/day capacity.

The U. S. Bureau of Mines Project Officer and the Project Director served as ex officio members.

Recycling and Reclamation

Historic Municipal Perspectives

Atlanta

The solid waste management program includes the use of heat from incineration for steam production and tin can salvage from incinerator residue.

The Mayson incinerator, a 350 tons/day capacity rotary kiln type plant, has waste heat boilers for steam production and tin can processing equipment. Two furnaces rated at 175 tons/day each were added in 1951. Cans are screened, washed, and crushed for shipment to the Southern Ferro Division of Tennessee Products and Chemical Corp., Nashville, Tennessee. Under five-year contracts, prices averaged $8.70 per gross ton, f.o.b. cars Atlanta. About 1960, process changes were made and a contract entered into with Proler Steel Corporation for shredded cans. The price under the arrangement at the time of the study was $11.50 per gross ton f.o.b. cars Atlanta.

A second incinerator of rotary kiln design with 500 tons/day capacity began operation in 1963, with provisions for a third 250 ton/day furnace. Waste heat boilers were not included in the second plant, but processing equipment for tin can recovery from residue was included. The gross tonnage of processed tin cans from both plants totaled 5,918 tons in 1967 and 5,609 tons in 1968.

There are no modern "shredding" plants for heavy metal processing in the Atlanta area, although one private processor has installed a 40-car-per-day "jalopy" incinerator with elaborate air pollution controls (electrostatic precipitators). Junked automobiles removed by the municipality are disposed of in landfills.

No past experience was reported in the salvaging of items from "raw" refuse at plants or landfills; such salvaging is neither permitted nor practiced at landfills.

Baltimore

Officials of the city reported past experience with salvage activities, but none with salvage of items contained in incinerator residue. Bright metal (not burned) was salvaged for foundry use (sash weights) from 1932 to 1941 but discontinued because of lack of markets. Heavy metallic refuse (bulky items) was salvaged until 1944 and discontinued because of rising labor costs and lack of market outlets.

Data for 1936 through 1939 indicated that approximately 13.5 million pounds were salvaged annually from raw refuse. Equivalent amounts of paper products and ferrous metal accounted for some 80 per cent of this total. The return approximated $35,000 annually. Several years ago, residue ash and clinker were tested as aggregate for cinder block, but the iron contained therein caused rust stains on the blocks and made them unsuitable for use. At present, there is no salvage by the municipality from refuse or incinerator residue.

Incinerator residue has been used for landfill and landfill road building for many years. Neither officials nor city employees have any knowledge of a request by industry to purchase tin cans or other residual metals from the city. Offers to haul bulky metal items free of charge directly to scrap processors have been rejected.

Cincinnati

A contract with a private firm in the early 1950's, which has not been renewed, reportedly yielded $25,000 annually to the city. About 20 persons were employed in the operation, which involved the use of a crane. Several persons were used to recover colored cullet.

Early in 1969 the city contracted with a private firm to salvage bulky items picked up in special collections. However, at the time of the case study visit, nothing had been hauled away and the firm had requested a release from the contract, including sacrifice of the bond.

Los Angeles

Experience with solid waste salvage was unique. Until 1957 household refuse, other than garbage, was burned in backyard incinerators; refuse collected by the municipality was low temperature incinerator residue. Since 1930, most of this residue has been delivered to a private salvage company for processing, and until 1951 contracts provided for payment to the city.

The copper mining industry served as the principal and most lucrative outlet; tin cans recovered and processed from residue were shipped to the mines. In addition to residues delivered by the municipality, the private salvage company also received considerable quantities of processable materials from other sources, including industry and private haulers. The average monthly production figures are shown in Table 2.

TABLE 2
Average Amount of Material Salvaged from Los Angeles Refuse by Corporation Contracting with Municipality Mid 1950's

Material	*Tons per Month*
Processed Tin Cans (from municipal noncombustibles) in addition to 1,000-2,000 tons per month from other sources	4,000-4,500
Flint and Amber Cullet	1,800-2,000
#2 Ferrous Bundles	200
Heavy Melting Scrap (sheared, etc.)	100
Nonferrous	40

Prior to 1950, for a year or two, some 2,000 tons per month of tin cans (surplus to copper mine needs) were baled and transported to a local steel company. But the cans were found to be deleterious to production quality needs and the practice discontinued. There has been no local market since.

Backyard incineration was halted in 1957 and a municipally-operated rubbish collection system instituted. To avoid the complete loss of previously recoverable items of metals and glass, the public was asked to separate them for collection every third week. In July, 1961, a two-year contract involving the separation of tin cans only by the householder was started. It provided for a much larger reimbursement to the municipality and contained a provision for a one-year extension. Based on $11.26 per ton, payments to the municipality for separately-collected metals were: 1961-62, $499,363.74; for 1962-63, $434,054.36; for 1963-64, $263,231.36; and the total for the three-year contract, $1,196,649.40.

Steady dimunition in payments during the contract period was reported to be the result of decreasing cooperation of householders due to unsympathetic official attitudes, infrequent service, and inconvenience. The cost of collection was reported to exceed salvage revenue by a substantial amount.

Milwaukee

No salvage operations exist at present, nor are any contemplated. The only use made of incinerator residue is as cover at the city's noncombustible dump areas. There are no salvage operations by private haulers.

The city has in the past received two or three inquiries a year regarding the use of tin cans from incinerator residue. Proposed use in recent years was for copper precipitation, but the low percentage of tin cans in the incinerator residue and high labor costs are cited as primary factors in making reuse uneconomical.

New Orleans

A 12-year contract with a local scrap processor, ending in the early 1960's, provided for salvage of tin cans and metal scrap from incinerator residue and landfills. The tin cans were shredded by the contractor and shipped to a Nicaragua copper mine. The contract yielded about $16,000 annually to the city. However, costs of hauling the solid waste to the processor were more than the value of the contract.

Because of the large demand for fill in the area, incinerator residue has historically been a usable commodity.

General Trends

The case studies reveal a generally uniform trend away from salvage of items in mixed household refuse, influenced by economic considerations and the absence of dependable market outlets. However, it can be attributed in some degree to the gradual changes in recent years in the methods and procedures of dealing with the overall problem. Three important elements of change which appear to have a marked effect on recycling efforts are:

1. The abolition of separation requirements for household garbage, rubbish, ashes, and noncombustibles in favor of "mixed" collection procedures for purposes of economy and convenience.

2. The imposition of outright bans against landfill salvaging because of its interference with wholesome conditions and proper operating procedures.

3. Strengthened air pollution standards, criteria, and controls, which have had tremendous impact on the use of combustion as a solid waste processing method.

The elements of change in solid waste management practices observed in the case-study cities offer little encouragement to the prospect of recovery of items for salvage from household refuse under municipal sponsorship, or to the private entrepreneur.

Present Patterns

Incinerator Residue

Atlanta salvages items in municipal incinerator residue through a mechanical separation by screening, followed by washing and shredding of tin cans for ultimate use by the copper mining industry. Gross tonnage of processed tin cans totaled 5,918 tons in 1968. The tin content in cans and iron oxides is as high as 0.3 per cent, although this is not important when the cans are used for copper precipitation. All remaining residue, including fly ash and grit recovered from spray chambers and quenching water respectively, is used for cover materials on landfills.

The cost of processing salvage metal from residue is of marginal benefit in Atlanta. No consideration is given to the principle of conservation of natural resources. Long-haul and limited landfill sites could have an impact on such an evaluation; on the other hand, the residue itself could be used as a source of cover material or fill without the expense of metals processing.

None of the other four case-study cities employing municipal incineration salvages from the residue at present. Residues, including fly ash and grit, are used for landfill cover or for building roads, and ferrous metals are not removed when the residue is used on landfills.

Salvage from Refuse

No case-study city reported salvage from municipally-handled solid wastes. It is significant that this includes Milwaukee where household bottles and cans are collected separately.

The same general pattern applies to the private sector, although private collections do practice some salvage of source-segregated items. Some route salvaging is practiced and some minor salvaging is practiced and some minor salvaging efforts are reported on a few privately operated landfills, the latter usually limited to paperboard and nonferrous metals. Limited outlets, low prices, and application of the interstate commerce provisions of the Wage and Hour Law were said to be the vital factors discouraging this approach. In Los Angeles, municipal officials reported the stated policy of the City Planning Agency is that "refuse is a resource for land reclamation."

Local Market Outlets

Nonferrous Metals. Scrap processors reported that unlimited and lucrative market outlets exist for clean nonferrous items. Considerable interest was expressed in the potential of trace element extraction from incinerator residue.

The marketability of contaminated aluminum ingots, a potential by-product of the recovery process, did not seem to pose insurmountable problems to the processors. A Baltimore processor indicated a potential ability to handle such ingots assayed at 70 per cent aluminum. Others expressed confidence that a market would exist with secondary aluminum smelters provided there was not too much zinc in the combination and the lead content did not exceed 1 per cent.

Two firms engaged in marine salvage concurred in the view that nonferrous salvage and engine salvage from ship dismantling are the prime factors economically justifying the venture under present conditions. The value of highgrade ferrous metals alone is generally not sufficient to justify such enterprises.

Ferrous Metals. Except for the mining industry, market outlets for ferrous metals contained in incinerator residue are uniformly reported to be nonexistent. Scrap processors reported the nonexistence of markets for low-grade scrap generally; the availability of high-grade scrap was said to preclude its marketability. Several processors indicated that if the ferrous metal fraction of incinerator residue were cleaned and refined to meet present minimum requirements for steel production, the impact of this limited quantity of scrap on the existing local scrap market would not be significant. Others said it would tend to depress the market. All were aware of the limited outlet for processed shredded ferrous for copper precipitation, an outlet which received about 400,000 tons of scrap annually.

The relative importance of the ferrous metal fraction of incinerator residue can hardly be overemphasized. Analyses of combined domestic refuse processed through high temperature incinerators indicate the ferrous fraction approximates 28 per cent of the residue on a dry weight basis. Because of the low specific gravity of loose tin cans, however, and the relatively high density of the remaining fractions of residue, the volume of ferrous metals in incinerator residue may range as high as 70 per cent. Such residue gives the appearance of being largely tin cans. The Midwest Research Institute reports that in the United States 6,794,000 tons of steel are converted annually to packaging and closures.

The deleterious effects of tin are consistently advanced as the principal reason tin can scrap generally is unacceptable to steel mills and foundries. Markets for baled bright tin cans are therefore nonexistent; even detinneries are averse to their use in loose form because of the presence of "dissimilar" materials under present day packaging techniques. It has been forecast that by 1976 some 50 per cent of all steel cans will be made from tin-free steels (TFS). This development would alleviate the tin contamination.

Considerable quantities of ferrous scrap are being exported to Europe and Asia from all the case-study cities except Atlanta, indicating the limited source of the domestic market for ferrous materials.

Glass.

In all six cities there is a demand for cullet in excess of present supplies. However, the amount of glass in the community solid waste burden greatly exceed the amount sought by glass manufacturing plants. Officials of all plants contacted expressed interest in any program of resource recovery in this area.

Cullet recovery has not been intensified for a number of reasons. Glass manufacturing techniques vary from plant to plant. The end products and batching procedures limit the type and quality of cullet that can be used. Production procedures are sensitive to plant wastes, due to culls and breakage, which are reusable as cullet. Should economical separation methods be developed to recover glass through an intensive solid waste salvage program, including incinerator residue salvage, supply would far exceed *present* local demand in every case.

Other Incinerator Residue Items

No meaningful information was provided by those interviewed to indicate any present or planned recycle use for grit, or other incinerator residue items. The use of fly ash as a pozzolanic material, as a soil conditioner, as a median for extraction of trace elements, and as an additive in the production of clay and cinder products has apparently not been given serious consideration.

Resource Recovery - Real and Potential

A number of salient facts emerge as common to the experience of the case-study cities. First, there is real interest in the principle of resource recovery among public and private solid waste management officials and industry managers. Second, there is a significant amount of recycle-reclamation activity being practiced but it involves only a small fraction of the solid wastes generated. Third, some process of segregation and "cleaning" of salvageable items is fundamental to practical reclamation systems management, but such segregation will not in itself assure a recycling program of items of solid wastes. Fourth, market outlets emerge as the key factor if resource recovery is to become an effective method of solid wastes "collection and disposal."

Incinerator Residue Processing

Source Segregation

Substantial quantities of commercial and industrial wastes are reclaimed through segregation at the sources of waste production. Recycle of metal turnings through scrap processors is one example; recycle of self-generated cullet wastes by glass manufacturing plants is another. On the other hand, household refuse is collected as "mixed" or "combined" material and therefore presents a heterogeneous mass embodying significant economic and technological separation challenges. Except for relatively minor efforts, programs for source segregation of domestic-household refuse are not in effect. Considerable research is being directed toward developing methodology for separating mixed refuse. Assuming separation is economically and technologically feasible, there remains the factor of contamination. Source separation, therefore, while a real potential consideration, must be considered a partial solution.

Value of Incinerator Refuse

The fact that one of the case-study cities maintains separate collections for combustible and noncombustible household refuse is the exception rather than the common practice. Assuming that incineration has been demonstrated as the economic solution to a community's solid waste disposal problem, it offers a potential "zero residue" end-point if resource recovery is practiced. Such a program envisions the removal of ferrous and nonferrous metals, recovery of glass, and refining of the remaining fly ash and residue to recover trace metals or other values. The remaining inert residue could then be used as a high-grade fill material. The technology required is presently the major thrust of the U. S. Bureau of Mines application and development work.

Such a program, to be successful, requires a properly designed and operated high temperature incinerator adequately designed to meet all load conditions and air pollution standards. It further requires adequate and continuing outlets for the material recovered.

Resource Recovery Outlets

Development of market outlets, whether economical or not, is fundamental to the success of expanded resource recovery programs.

Despite the "combined material" approach in packaging, aluminum recovery prospects appear to be feasible under the incinerator residue processing approach. While full cooperation of the glass container industry can be anticipated in the use of cullet, case-study findings indicate that potentially salvageable amounts would swamp the industry. Alternative uses and new product approaches in this area are vital.

The use of shredded ferrous metal for copper precipitation purposes is a very limited outlet, from a nationwide standpoint. There are serious problems with domestic market outlets for high-grade scrap. If ferrous salvage, low-grade or detinned, is to be successful, new markets are an absolute requirement.

From a resource recovery and recycling standpoint, "market outlets" to processors or brokers mean profitable outlets. From a refuse disposal standpoint, "outlets" for recoverable items are essential and must be assured on a firm basis for long-range periods before "salvage" procedures can be entertained. Subsidies that stimulate the profit motive do not necessarily provide "outlets," although they might aid in generating them. Subsidies that support research and development, while helpful, may be unable to resolve fully the fundamental problems.

An important factor is the public demand for high-grade products and industry's competitive mission to supply them. Sometimes virgin resources are the preferred raw material. Recycling efforts almost always are "part and parcel" of plant operations wherever use of plant wastes is practicable and economical and the recycled items *meet quality specifications*. Meeting specifications for normal industry recycling purposes with crude and contaminated items which are such a large proportion of community waste poses a severe problem.

The reluctance of solid waste management officials—and in recent years private entrepreneurs—to engage in any large-scale operations of this nature can be ascribed largely to outlet limitations. Rapid or revolutionary changes in their attitude hardly can be expected unless there are fundamental changes which create the outlets needed to stimulate solid waste management recovery programs.

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Community and Industry Look at Solid Waste Management

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Every community has pollution problems. Some are meeting the challenge effectively, others are not. Industrial-community relationships are often very strained because of the divergence of viewpoints concerning the methods and schedule sought for the control of pollution. However desirable it may appear to be, the time has come when neither the community nor industry can ignore the other's problem.

Generally, industrial waste characteristics, local practice, and local preference have separated community solid waste into two portions. The larger portion representing solid wastes from community households, the lesser quantity being industrial-commercial waste, lesser in quantity but more difficult to handle because of unusual form and specific content.

Community concern for the environment now requires a total evaluation of environmental problems. While the collection and disposal of total community solid waste may be done separately, the effect of the method or methods in use produces an environmental impact felt by the community as a whole. Recent anti-pollution activities have made it quite clear that we can no longer address ourselves to one pollution or a single pollution source at a time, we must consider the total environment in all our activities.

With the advent of more stringent solid waste management criteria, many industries and communities will be cooperatively exploring solutions to their common problems.

As is the case in most environmental applications, we judge the problems relatively. We relate to the problem in terms of our own experience. Unless we exert extra effort we may perceive the wrong problem. The handling of industrial waste solids is a part of the total solid waste problem but does not represent the heterogeneous solid waste problems known to community officials.

Industries are in control of waste resulting from their processes, few communities can exercise much control of the forms, amounts, or times of solid waste receipt. As a matter of fact, most communities can only predict that solid waste parameters will be unpredictable and that systematic treatment of all wastes generated within the community is beyond the realm of community solid waste management, especially without considerable assistance from the contributing sources.

Municipal solid waste managements often express the desire for a more predictable homogeneous product to handle, not recognizing the fact that present solid waste handling systems are designed to handle the heterogeneous. Community solid wastes containing a relatively small portion of tomato waste is easily handled — 100 percent tomato waste create havoc when processed through the identical system. One pressurized can can, be easily handled — one thousand, creates a rather explosive situation. A small portion of industrial sludge can be mixed with the normal community refuse — a refuse containing a high percentage of industrial sludge presents the need for an entirely new approach. While the typical municipal system operator indicates a desire for homogeneity, the currently used handling methods cannot accommodate these materials if so presented.

In many areas, industry can be commended for the elimination of waste. Most of the examples are not recognized as waste prevention methods, but are considered the economical utilization of process by-product. As we begin to include the value of our environment in process accounting, more of industrial waste will become economically attractive as a resource. New process systems will be developed never to be called solid waste management but rather included as a process system.

It appears that the application of industrial technology to solid waste management could provide a very important reduction in solid waste quantities. Patterned after similar industrial operations, it is obvious that solid waste which has been utilized in another product is a materials resource. When used in this manner, it is never identified as a waste or waste product. In contrast, the community challenge is to sort and separate such materials as may be available for recycle, reducing the total amount of material already labeled "waste" or "waste product."